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Turnaround Operations Analysis for OTV

Final Report

Volume II Detailed Technical Report

February 1988

The cost estimates contained herein represent technical and programmatic definition developed to date and may change as further technical information becomes available. These estimates are for planning purposes only and do not constitute a commitment on the part of General Dynamics.

Prepared for

NASA-Marshall Space Flight Center
Huntsville, Alabama

Prepared by

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FOREWORD

This study report was prepared by General Dynamics Space Systems Division (GDSS) for the National Aeronautics and Space Administration Marshall Space Flight Center (NASA/MSFC) in accordance with Contract NAS 8-36924, Data Requirement Number DR-4. The results were developed from August 1986 to January 1988.

This volume describes the detailed analyses performed for ground processing both expendable and reusable ground-based orbital transfer vehicles (GBOTVs) launched on the Space Transportation System (STS), a reusable space-based OTV (SBOTV) launched on the STS, and a reusable GBOTV launched on an unmanned cargo vehicle and recovered by the Orbiter. This volume also contains the detailed analyses performed for space processing the reusable SBOTV at the Space Station in low Earth orbit (LEO) and the maintenance/servicing of the SBOTV accommodations at the Space Station. In addition, the candidate OTV concepts design and interface requirements are presented along with the Space Station design, support, and interface requirements. Finally, the development schedule and associated costs for the required SBOTV accommodations at the Space Station are presented.

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SUMMARY

The Turnaround Operations Analysis for Orbital Transfer Vehicles (OTV) Study was conducted by General Dynamics Space Systems Division (GDSS), Contract No. NASA8-36924, under the direction of the National Aeronautics and Space Administration (NASA)/Marshall Space Flight Center (MSFC).

The basic study was for 12 months with an add-on which brought the total time to 18 months. The results of the total study are presented in this final report.

The objectives and accomplishments during this study were to adapt and apply the newly created database of Shuttle/Centaur ground operations. Previously defined turnaround operations analyses were to be updated for ground-based OTVs (GBOTVs) and space-based OTVs (SBOTVs), design requirements identified for both OTV and Space Station accommodations hardware, turnaround operations costs estimated, and a technology development plan generated to develop the required capabilities.

The study provided technical and programmatic data for NASA pertinent to OTV ground and space operations requirements, turnaround operations, task descriptions, timelines and manpower requirements, OTV modular design and booster and Space Station interface requirements, OTV Space Station accommodations design and operations requirements, SBOTV accommodations development schedule, cost and turnaround operations requirements, and a technology development plan for ground and space operations and space-based accommodations facilities and support equipment. Significant conclusions of the effort were:

a. Shuttle/Centaur Lessons Learned

1. Semi-automated cryo stage can be extended to full automation
2. Identified manual operations: candidates for automation
3. Airborne support equipment (ASE) for ground-based cargo bay OTV will be complex (dump and dual fault tolerant)
4. Dedicated facility recommended
5. Facility should provide capability to simulate launch vehicle interfaces and Space Station interfaces
6. Reduce number of moves

b. Ground Processing Operations for GBOTVs

1. Ground processing of ground-based cargo bay OTVs nearly identical to Shuttle/Centaur

2. Ground processing of ground-based unmanned cargo vehicle (UCV) OTVs similar to Atlas/Centaur and Shuttle/Centaur

3. Ground processing of space-based OTV relatively simple
   (a) Simple ASE
   (b) No orbiter cryo integration
   (c) No payload integration

4. Recommend integrated processing facility for GBOTVs: Two shift operations

5. Automated ground processing operations where possible

6. GBOTV initial launch 6 weeks (9200 manhours)

7. Nominal turnaround GBOTV 5 weeks + mission (7800 manhours)

8. UCV OTV initial launch 5 weeks (6500 manhours)

9. UCV OTV nominal turnaround 5 weeks + mission (6200 manhours)

10. Recommend shared ground processing facility for SBOTV

c. Ground Processing Operations SBOTV

1. Ground processing of space-based OTV relatively simple
   (a) Simple ASE
   (b) No orbiter cryo integration
   (c) No payload integration

2. Recommend shared ground processing facility for SBOTV

3. SBOTV single shift operations - Initial Launch 11 weeks (10,332 manhours)

d. Space Processing Operations SBOTV

1. SBOTV can be based at Space Station and turned around in safe and cost-effective manner

2. Use teleoperations for SBOTV turnaround tasks except for aerobrake thermal protection system: extravehicular activity (EVA)

3. Nominal turnaround for SBOTV:
   (a) 63 manhours in space
   (b) 763 manhours on ground
   (c) 7 days + mission

4. SBOTV turnaround propellant resupply, support equipment maintenance, and long-term cryogenic facility maintenance = 1273 manhours per year average at the Space Station (3 men maximum per task)

e. OTV Design and Interfaces

1. Need proposed modular design of SBOTV to meet projected turnaround times

2. Interfaces between OTV launch vehicle and accommodations have been identified

f. Space Station Design, Support, and Interface Requirements

   1. SBOTV accommodations/support equipment and interfaces with the Space Station have been identified

   2. Minimum scars required on initial Space Station for SBOTV accommodations

g. Support Equipment Development Cost and Schedule

   1. Development of OTV accommodations technology requires
      (a) Analyses, tests, and simulations on the ground
      (b) A cryogenic experiment on an expendable launch vehicle (ELV) in space, and Shuttle sortie missions for maintenance/servicing experiment
      (c) A maintenance/servicing Technology Development Mission (TDM) and possibly a cryogenic TDM at the Space Station

   2. $1.4 billion development cost for OTV accommodations/support equipment for SBOTV initial operating capability (IOC) in 2001

h. Turnaround Operations Costs. Average $34M per year for on-orbit tasks to turnaround a SBOTV

i. Technology Development Plan. The following is the priority listing of the technologies needed to be developed for a SBOTV:

   1. Propellant transfer, long-term storage, and reliquefaction

   2. Automated fault detection/isolation and checkout system

   3. Docking and berthing

   4. Maintenance/servicing operations and facilities/support equipment

   5. Payload mating/interface

j. Propellant Transfer, Long-Term Storage, and Reliquefaction Technology Development Requirements

   1. Analyses, simulation and ground testing

   2. An orbital experiment launched on an ELV with a H_2 tank scale factor between 0.1 and 0.4

   3. Depending on the scale factor on the ELV experiment which produces different confidence levels of extrapolation to full scale, these options are seen to be able to reach operational capability
      (a) 0.4-scale ELV (Titan IV) can lead to direct development of operational system
      (b) 0.1-scale ELV (Atlas/Centaur) would require additional full-scale ground testing, or
      (c) Full scale H_2 tank testing at the Space Station

   4. Too early to recommend which approach should be pursued

k. Automated Facility Detection/Isolation and Checkout System. Development of GBOTV and SBOTV operation technology requires analyses, simulation, and ground testing of automated fault detection/isolation and checkout system.

l. Maintenance/Servicing Operations and Facilities/Support Equipment. Development of SBOTV accommodations technology requires analyses, simulation, ground testing, and Shuttle sortie missions, and a Space Station TDM for docking and berthing, maintenance/servicing, operations/support equipment, and payload mating/interface.

SECTION 1

INTRODUCTION

The Orbital Transfer Vehicle (OTV) Concept Definition and System Analysis Studies, and earlier Space Station Architecture Studies, have shown that space-based OTVs (SBOTVs) offer potential economic benefits over ground-based OTVs (GBOTVs). In addition, the Definition of Technology Development Missions for Early Space Station -- OTV Servicing Study, completed in 1984 and the present OTV Concept Definition Studies have generated preliminary operational scenarios and requirements for SBOTVs.

The General Dynamics Space Systems Division (GDSS) OTV Servicing Study used our Eastern Test Range (ETR) Atlas/Centaur processing as a data base. This has provided a sound background for a preliminary projection of activities to maintain and service an upper stage in space. Recently, the design, launch processing, and manufacture of the Shuttle/Centaur was essentially completed. The launch processing was performed up to taking the stage out to the launch pad before the program was cancelled. The Centaur, redesigned for increased performance and Shuttle integration requirements, is closer to an OTV than the vehicle used on Atlas.

Now that the Shuttle/Centaur integrated test planning data and launch processing has been completed, GDSS has used this information as the data base for the conduct of this follow-on study. Processing information has been updated with this new data. In addition, with this new data, it was possible to provide more detailed information on the most desirable methods for turning around an SBOTV at the Space Station, the support personnel and equipment needed, and the operations costs. The Shuttle/Centaur data base -- that of a cryogenic upper stage launched from the Shuttle -- has provided National Aeronautics and Space Administration (NASA) a comprehensive, substantiated turnaround approach for Space Station/OTV planning.

The Space Transportation Architecture Studies (STAS) currently being performed for NASA and Department of Defense (DoD) have placed strong emphasis on the reduction of operations costs through simplification, automation, etc. This turnaround operations analysis study provides additional information to support the pursuit of this cause in the upper-stage area.

1.1 OBJECTIVES

The basic objectives of this study are to adapt and apply the newly created data base of Shuttle/Centaur ground operations planning to update previously defined turnaround operations analyses for GBOTVs and SBOTVs, identify design requirements for both OTV and Space Station accommodations hardware, and estimate turnaround operations costs. Specific objectives which support these basic objectives are as follows:

a. Define OTV turnaround operations requirements, concepts, and scenarios.

b. Conduct operations functional and task analyses.

c. Assess the impact of OTV turnaround operations on ground facilities and Space Station design and support requirements.

d. Identify OTV design requirements of effective turnaround operations.

e. Analyze turnaround operations costs and identify operations costs drivers.

f. Generate Technology Development Plan.

1.2 GROUND RULES AND GUIDELINES

The following ground rules and guidelines were used in the performance of this study:

a. Make maximum use of prior and current projects.

b. Space Shuttle will be the Earth launch vehicle: $100M [Eastern Launch Site (ELS)].

c. Revision 8 nominal mission model.

d. Space Station Initial Operational Capability (IOC) 1994.

e. Orbital Maneuvarable Vehicle (OMV) will be available.

f. Orbiter Cargo Bay (OCB), Aft Cargo Carrier (ACC), and Unmanned Cargo Vehicle (UCV) Launched
GBOTVs

g Reference SBOTV configuration: Defined by Marshall Space Flight Center (MSFC) for Space Station Phase B.

h. SBOTV life is 40 missions.

i. Definition of a Task: Any activity or collection of activities serving a specified purpose relative to turnaround of the OTV.

j. Definition of a Resource: Any quantity required for the performance of a task: Each resource will be defined to appropriate depth for concept definition.

k. Functional tasks will be completely defined.

l. Tasks sequencing information will be provided.

m. Functional/task data base compatible with government computers.

1.3 OTV MISSIONS

The OTV will accomplish a wide range of missions, from Earth orbital to lunar and planetary, both unmanned and manned. (See Figure 1-1.) Routine transfer of civilian and military payloads between low Earth and geosynchronous orbit are planned, including delivery, retrieval, and in-place servicing. The operational scenario and mission profile of the OTV include: initial delivery of the OTV with subsequent delivery of payloads and propellants from the Earth to the OTV/servicing facility by either the Space Transportation System (STS) of unmanned launched vehicles; integration of payloads on the OTV and refueling of the OTV from propellant storage tanks on the servicing facility; departure of the OTV and payloads to high orbits, translunar, or interplanetary trajectories; then return of the OTV via aerobraking to the servicing facility.

Earth orbital
- Multiple GEO payload delivery
- Large GEO satellite delivery
- GEO satellite retrieval
- Experimental GEO platform
- GEO shack elements
- Manned GEO sortie
- GEO shack logistics
- DoD

Beyond earth
- Unmanned planetary
- Unmanned lunar orbit
- Unmanned lunar surface
- Lunar orbit station
- Manned lunar sorties/logistics

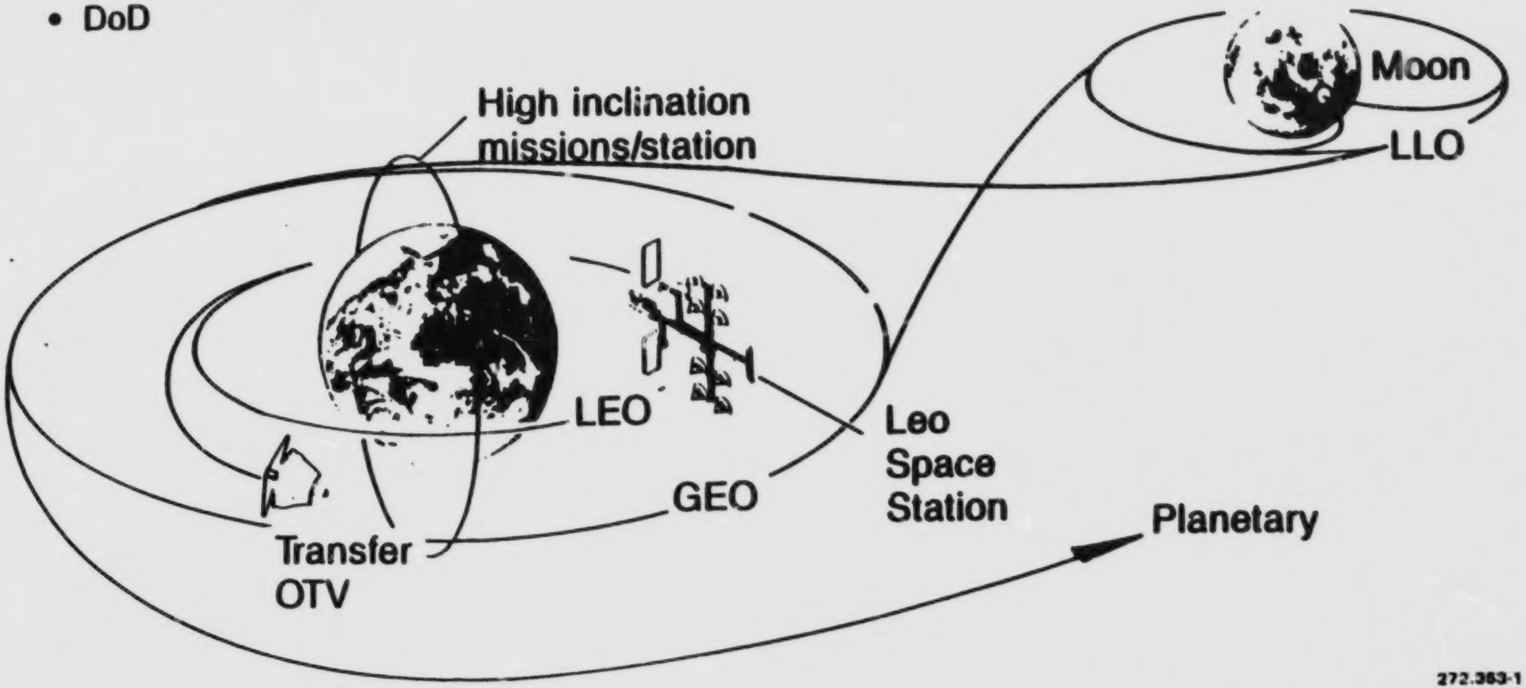

Figure 1-1. OTV Missions

For purposes of this study, NASA has specified that the NASA/MSFC Revision 8 nominal mission model be used. Figure 1-2 indicates the number of missions to be performed each year for Revision 8 and when the major mission drivers first occur.

1.4 STUDY APPROACH

The overall approach to this study will be a step-wise translation of Shuttle/Centaur launch processing experience to: 1) an expendable GBOTV, 2) a reusable GBOTV, and 3) a reusable SBOTV. (See Figure 1-3.) Each step will be separately defined to allow a clear delineation of the functions and requirements which are peculiar to each vehicle/basing mode. The major differences between each step are called out to the right of the blocks.

This approach provides more insight for extrapolation from Shuttle/Centaur launch processing to a reusable SBOTV.

Figure 1-4 presents the study schedule, delineating the tasks to be performed and the program reviews. The technical work was accomplished in 16 months with the reporting completed in 18 months.

To accomplish the study objectives, OTV turnaround operations requirements, concepts, and scenarios were defined; operations functional and task analyses were conducted; the impact of OTV turnaround operations on Space Station design and support requirements was assessed; OTV design requirements for effective turnaround operations were identified; turnaround operations costs were analyzed; and operations cost drivers were identified. In addition, a technology development plan was generated to develop the capability to process both GBOTVs and SBOTVs.

1.4.1 TASK 1 - GROUND AND SPACE OPERATIONS REQUIREMENTS. The Shuttle/Centaur ground processing data base was used to assess and identify requirements for OTV processing. As we evaluated the data base, we determined which operational functions were Centaur peculiar and which ones were required for OTV processing. The data consisted of operations plans which established the processing and critical paths for Shuttle/Centaur at the ELS. The plan had about 155 tasks defined and listed about 90 procedures to be accomplished during Centaur processing, before it was transported to the vertical processing facility. The operations plans for the vertical processing facility and Complex 39 were also assessed. This was the type of data that we used to determine if all processes had been identified in the current OTV space-based operations. We then updated the OTV data previously defined to include the requirements identified here.

The Shuttle/Centaur data base also included manpower loading for each task and equipment requirements.

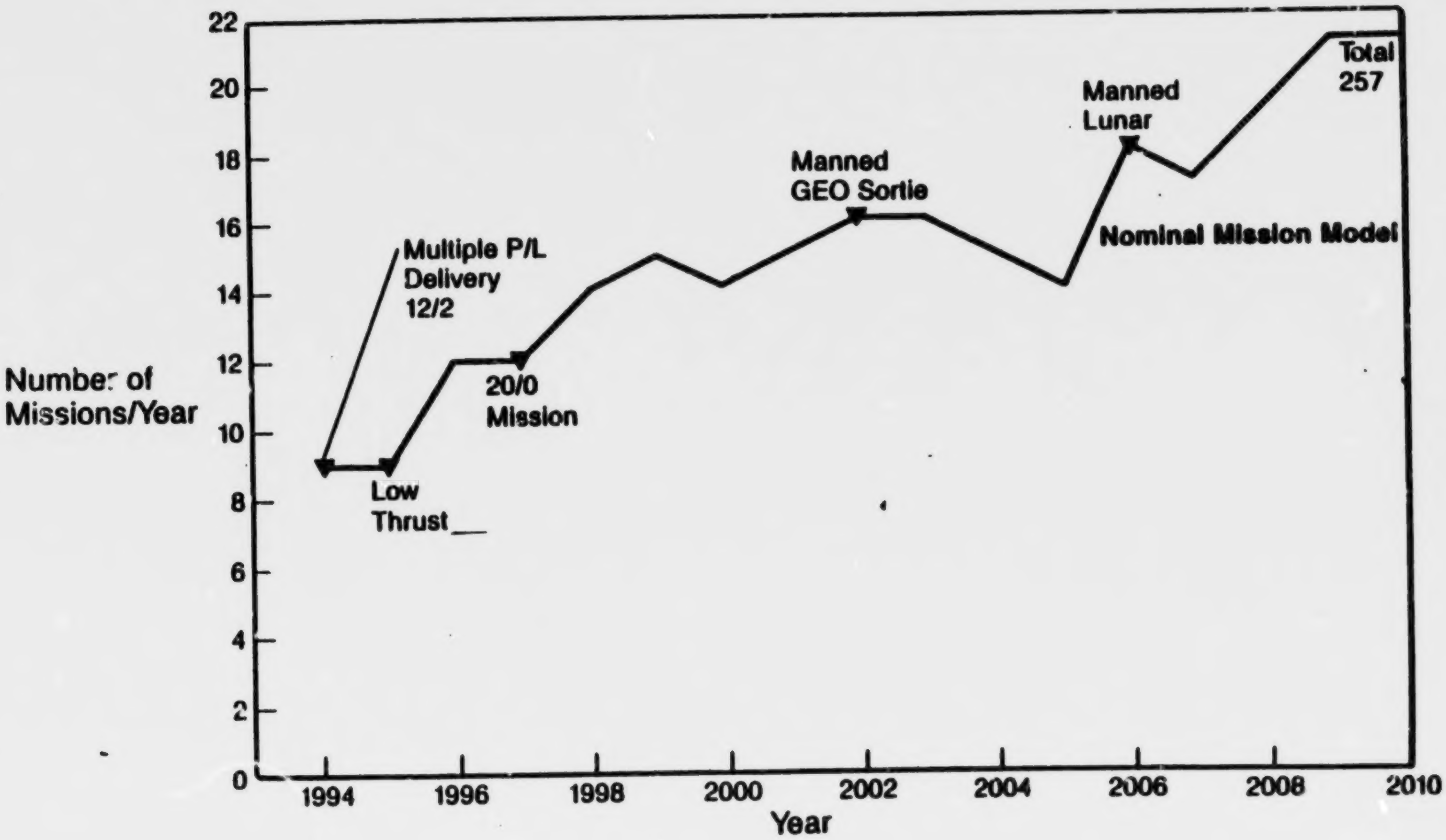

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Figure 1-2. Revision 8 Mission Model

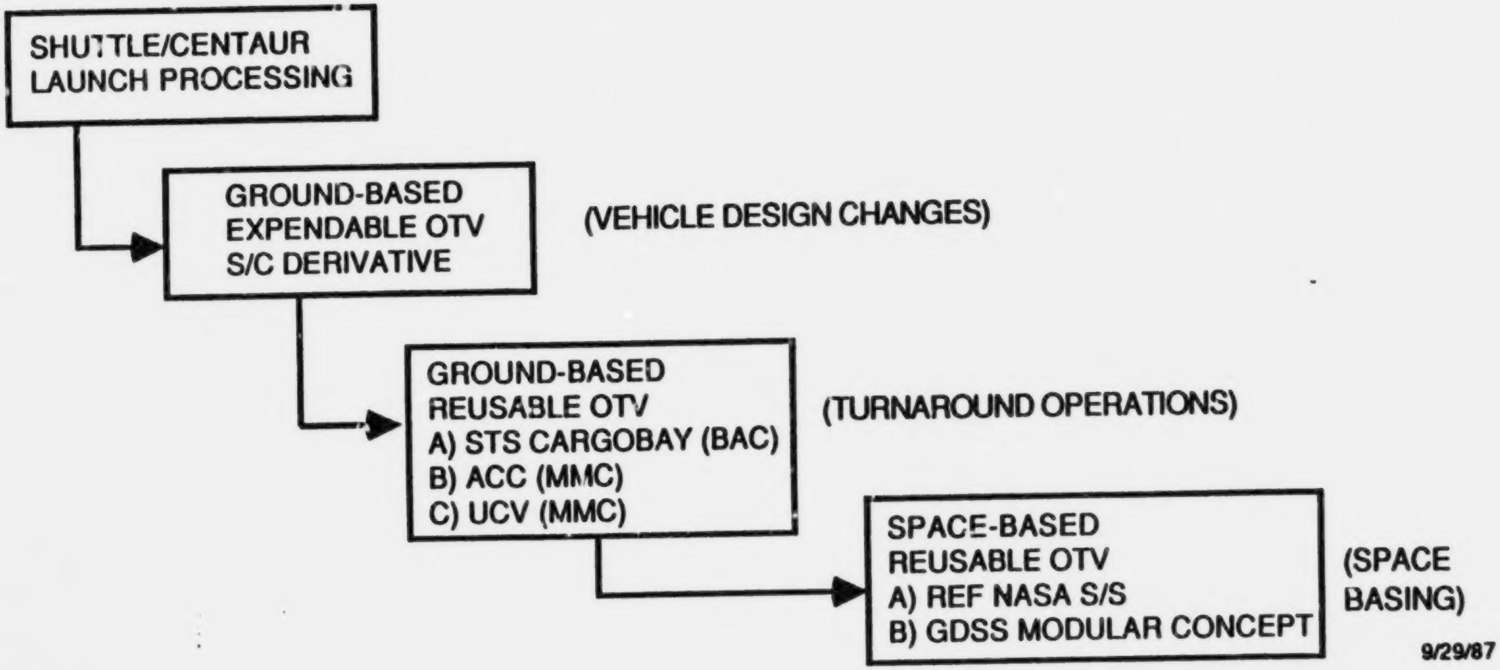

Figure 1-3. Approach

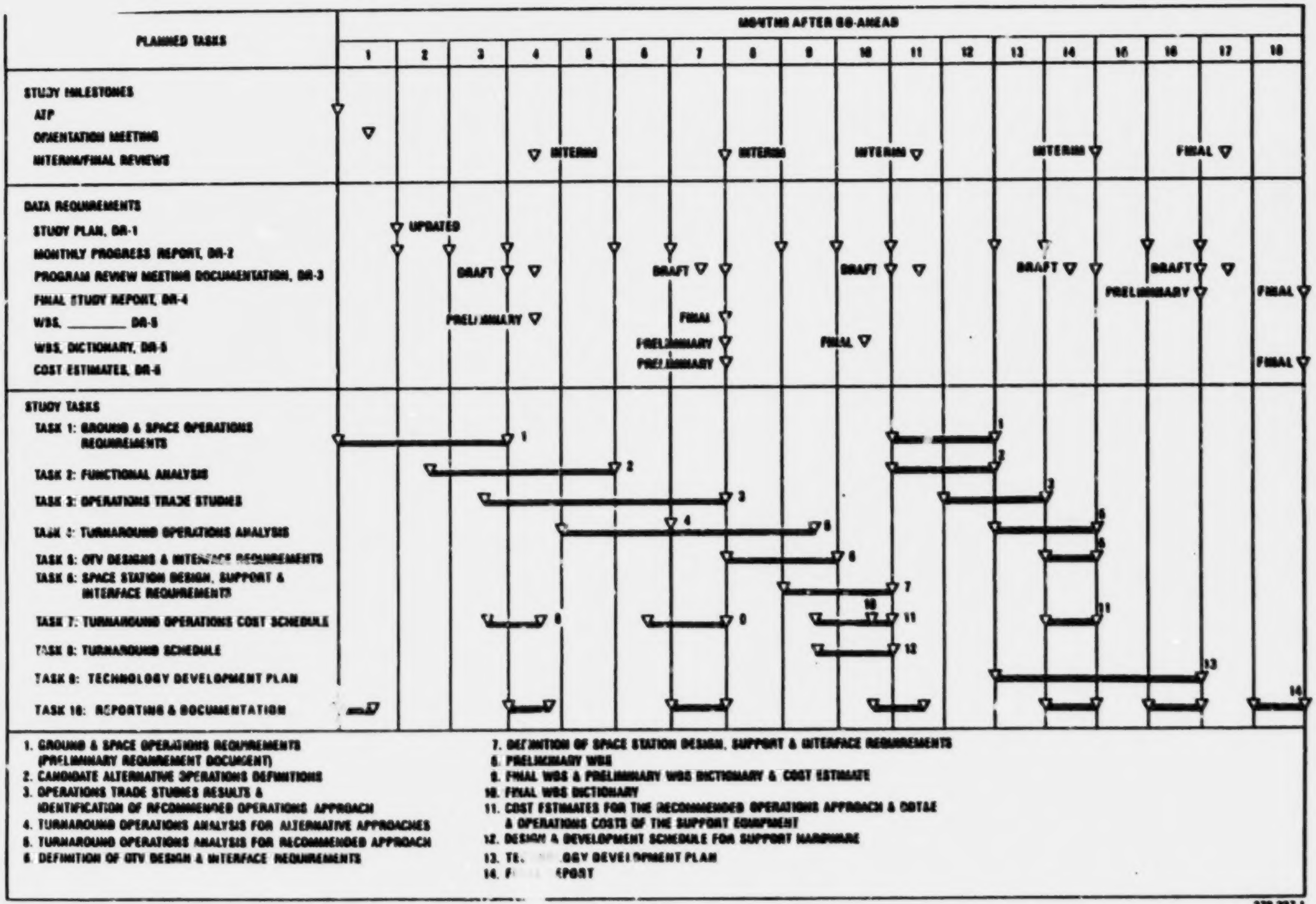

Figure 1-4. Study Schedule

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1.4.2 TASK 2 - FUNCTIONAL ANALYSIS. The requirements identified in Task 1 were integrated with other requirements such as guidelines and ground rules, Space Station configuration baseline, the SBOTV concept defined by NASA/MSFC to arrive at probable scenarios for processing. We looked at these requirements and determined whether they were essential for maintaining and operating an OTV. Any potential tall poles were identified, and all functional requirements were documented. The functional analysis includes the operations necessary to assemble a SBOTV on-orbit, space-based turnaround operations, servicing/maintenance, payload integration, launch and retrieval operations. We assessed these functions and incorporated any new requirements that were essential and appropriate and deleted or modified those that were not appropriate.

We formulated alternative scenarios from the functional requirements and defined operational methods for accomplishing each alternative scenario. These methods incorporated alternative means to accomplish each task, such as different types of facilities and automation for ground processing and different kinds of crew involvement, extravehicular activity (EVA) or intravehicular activity (IVA), and mechanized alternatives such as teleoperations, automatic disconnects on the vehicle, robotics, or a combination for SBOTV. These alternatives and the designated GBOTV concepts were compared in a trade study analysis to select a recommended approach in Task 3.

1.4.3 TASK 3 - OPERATIONS TRADE STUDIES. In this task we compared the attributes of each alternative operation identified in Task 2 to select a recommended approach. We defined the selection criteria used to evaluate the alternative operations. These criteria included design, operational, and cost factors that have an impact on the selection of a recommended approach. This task relied on inputs from Tasks 4 and 7 to provide adequate supporting data for evaluation of the approaches. The alternatives and selection criteria were then presented in a trade comparison matrix. The recommended operations approach was selected using the data from this matrix.

1.4.4 TASK 4 - TURNAROUND OPERATIONS ANALYSIS. This task generated the timeline analyses for both ground and space processing based on the requirements and alternative operational definitions derived in Tasks 1 and 2. These analyses provided the OTV turnaround operations data necessary to support the trade studies and to develop to more detail the trade study recommended operations by defining the ground-based and space-based resources.

We updated the existing OTV timelines to meet new requirements and created new timelines for new alternative functions. The timelines include OTV turnaround operations on the ground and in space and the maintenance of any identified Space Station OTV accommodations, such as orbital support equipment. Our timelines were created from data that was developed on task analysis worksheets. The task analysis worksheets are on computer disc and are used to document the pertinent detailed tasks, task durations, and resulting manhours. We also provided data to an appropriate level on task description sheets. The task description sheet has the task identification code, task descriptor, purpose, task description, task duration and frequency, and the resource requirements.

1.4.5 TASK 5 - OTV DESIGN AND INTERFACE REQUIREMENTS. Using the results and recommendations of the turnaround operations analysis and the definition of the baseline GBOTV and SBOTV, we identified and defined OTV design and interface requirements for basing on the ground and at the Space Station. These covered the areas of accessibility, modularity, size, and weight of Orbital Replacement Units (ORUs); ORU attachment and removal provisions; controlled storage; self-test to the ORU or subsystem level; handling and mating provisions; payload mating provisions; accommodations for mechanical, fluid, and electrical disconnects; zero-g propellant transfer; and management system, etc.

1.4.6 TASK 6 - SPACE STATION DESIGN, SUPPORT AND INTERFACE REQUIREMENTS. Using the definition of the space-based support equipment, the operational maintenance, checkout and launch requirements, the definition of an SBOTV to meet the operational and interface requirements, and the baseline Space Station functional and design concept, we performed a design requirements analysis to determine the accommodation needs from the Space Station to support the SBOTV. This entailed identifying the operational and physical Space Station support and interface requirements to accommodate the retrieval, maintenance, servicing, checkout, payload mating, and launching of the OTV. These included the mechanical, fluid and electrical interfaces; cg considerations; spares storage; pressurized volume; propellant transfer, and storage system; docking, berthing, and handling equipment; environmental protection; and crew support requirements.

1.4.7 TASK 7 - TURNAROUND OPERATIONS COST ESTIMATES. A WBS and WBS dictionary was developed which was used in the performance of the trade studies. The task's costs of the recommended operational approach considering the manpower resources required were estimated. The operational costs were divided into two categories: fixed and variable costs. Fixed costs are associated with a base cost not dependent on the number (within limits) of OTVs processed during a period of time (normally 1 year). Operation cost drivers were also identified. The design development test and evaluation (DDT&E) and operations costs of the support equipment for the recommended operational approach were also identified.

1.4.8 TASK 8 - TURNAROUND SCHEDULE. We developed a master program development schedule for the OTV and the evolution of the Space Station from IOC to the growth station which can support an SBOTV. From this, we generated a design and development schedule for the turnaround operations support hardware. The schedule included the technology development activities including analysis and ground testing, Shuttle sortie flights and Technology Development Missions (TDMs) required at the Space Station to develop the turnaround operations capability.

1.4.9 TASK 9 - TECHNOLOGY DEVELOPMENT PLAN. We generated an integrated technology development plan for the technologies required for ground and space processing OTVs. This was a single plan which defined the tests and experiments to be performed on the ground, on expendable flight experiments, on Space Shuttle sortie missions, and on the early Space Station. The ground processing technologies included: 1) fault detection/isolation and system checkout, 2) visual inspection, 3) leak check and detection, 4) documentation, and 5) facility checkout and operations provisions.

The space processing technologies included: 1) propellant transfer, storage, and reliquefaction, 2) OTV docking and berthing, 3) EVA operations, 4) OTV/payload mating, 5) maintenance facilities/support equipment, and 6) automated fault detection/isolation and system checkout. The plan included task objectivas, requirements, mode of accomplishment, schedules, resources, operations, and expected products. The plan reflected and accommodated current and projected research and technology programs where appropriate.

1.5 OTV CONFIGURATION

Configurations evaluated for functional differences (See Figure 1-5) include Atlas/Centaur; Shuttle/Centaur; Shuttle/Centaur derivative expendable OTV; Boeing Ballute OCB launched reusable GBOTV: Martin ACC launched reusable GBOTV; and SBOTV (MSFC reference configuration). In addition the Martin UCV OTV (see Figure 1-6) was evaluated. The configurations will be shown in more detail in the following sections.

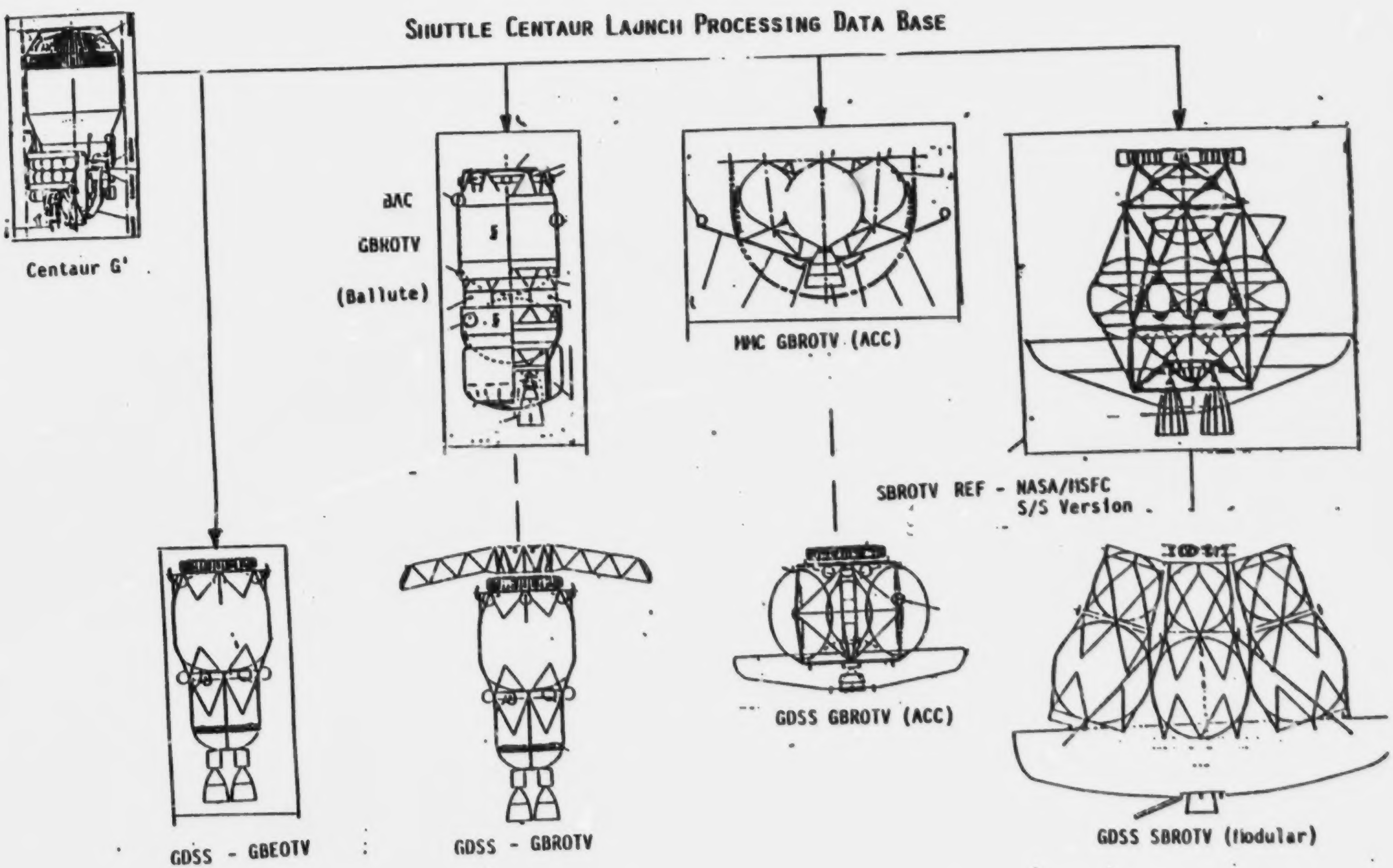
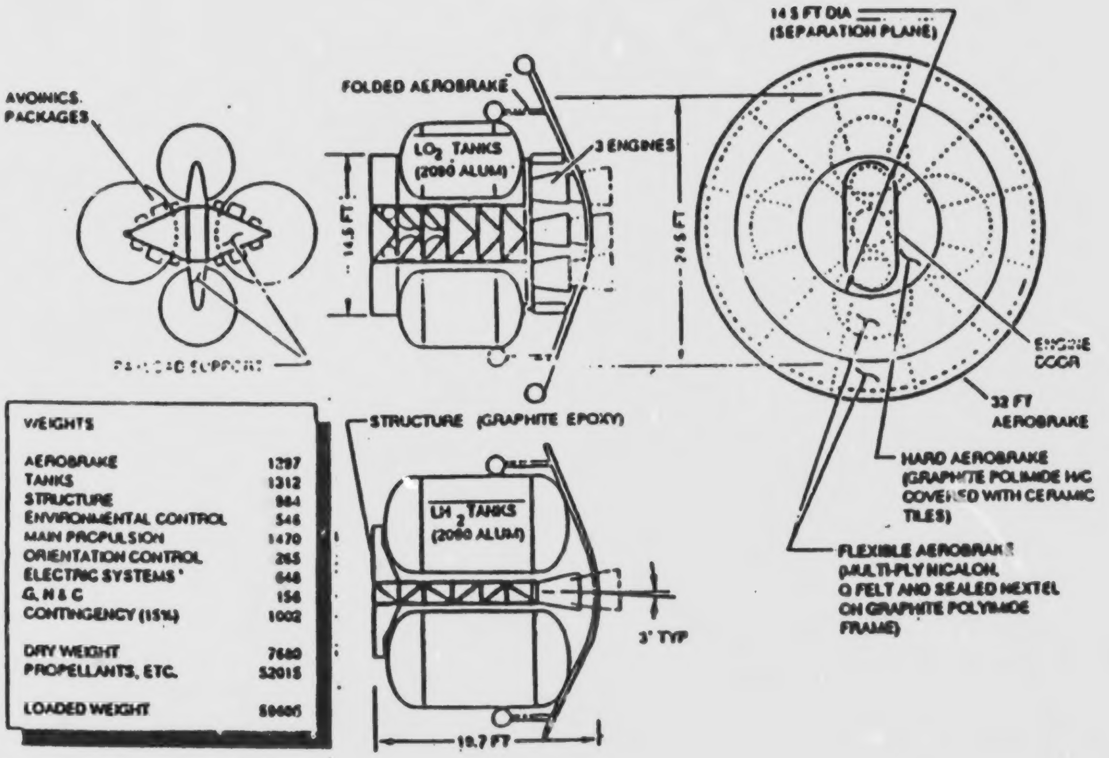


Figure 1-5. OTV Configurations


AVONICS PACKAGES
PAYLOAD SUPPORT
FOLDED AEROBRAKE
LO2 TANKS (2090 ALUM)
3 ENGINES
14.5 FT
24.5 FT
14.5 FT DIA (SEPARATION PLANE)
ENGINE DOOR
32 FT AEROBRAKE
HARD AEROBRAKE (GRAPHITE POLIMIDE H/C COVERED WITH CERAMIC TILES)
FLEXIBLE AEROBRAKE (MULTI-PLY NICALON, Q FELT AND SEALED NEXTEL ON GRAPHITE POLYIMIDE FRAME)
STRUCTURE (GRAPHITE EPOXY)
LH2 TANKS (2090 ALUM)
3' TYP
19.7 FT

WEIGHTS	
AEROBRAKE	1297
TANKS	1312
STRUCTURE	984
ENVIRONMENTAL CONTROL	546
MAIN PROPULSION	1470
ORIENTATION CONTROL	265
ELECTRIC SYSTEMS *	648
G, N & C	156
CONTINGENCY (15%)	1002
DRY WEIGHT	7680
PROPELLANTS, ETC.	52015
LOADED WEIGHT	59695

Figure 1-6. Unmanned Cargo Vehicle (UCV) OTV - Martin

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SECTION 2

SHUTTLE/CENTAUR PROCESSING DATA BASE

In previous OTV definition and servicing studies, the Atlas/Centaur ground processing data base was used to derive OTV processing requirements. Now, the Shuttle/Centaur data base, which has remarkable fidelity to proposed OTVs, is being used to update the existing data. However, there are such differences between Atlas/Centaur and Shuttle/Centaur processing, along with the completeness of the new data that Shuttle/Centaur data dominates this OTV operations analysis.

2.1 ATLAS/CENTAUR AND SHUTTLE/CENTAUR COMPARISONS

The primary and most obvious difference between the two vehicles was the requirement for Centaur integration with the Shuttle Orbiter. (This requirement has far-reaching design impacts and processing constraints.) The physical integration was accomplished with airborne support equipment (ASE), which met the shuttle dual-fault-tolerant safety and propellant dump requirements. These requirements drove the design to result in rather complex ASE. It was more desirable to incorporate the requirements into the ASE and not the vehicle to avoid weight penalties during space flight. The Shuttle/Centaur vehicle was also widened to fit Orbiter cargo bay dimensions as can be seen in Figure 2-1.

The Shuttle/Centaur is 29.5 feet long and 15 feet in diameter (fully using the Orbiter payload bay) and holds 46,285 pounds of propellants in the Ulysses (International Solar Polar Mission) configuration. There was also a Shuttle/Centaur G version which was 20 feet long and held approximately 30,133 pounds of propellants.

The Centaur stage used in the Atlas/Centaur launch vehicle is shown in Figure 2-2. It is 30 feet long and 10 feet in diameter and holds 29,750 pounds of propellants, with the capability of delivering a 5000-pound satellite to a geo-transfer orbit.

The Shuttle/Centaur ASE, called the Centaur integrated support system (CISS), is shown attached to the vehicle in Figure 2-3. The CISS depicted in Figure 2-4 in the Orbiter cargo bay without the Centaur vehicle was used to structurally secure the vehicle to the Orbiter and to rotate it to launch attitude. There were numerous interfaces, both fluid and avionics between the Centaur, CISS, and Orbiter. Besides the Centaur/CISS interfaces shown in the figure, there were also LO_2 and LH_2 fill, drain, dump, vent, and servicing lines associated with the Orbiter interface and all of these interfaces were connected and verified fairly late in the ground operations sequence.

There was also a difference in the level of automation during ground tests between the two vehicles. The Shuttle/Centaur operated in a semi-automated mode during ground tests because a manual interrupt was desirable for first time testing and during Orbiter integrated testing. Eventually the ground testing would have been extended to full or near full automation as planned

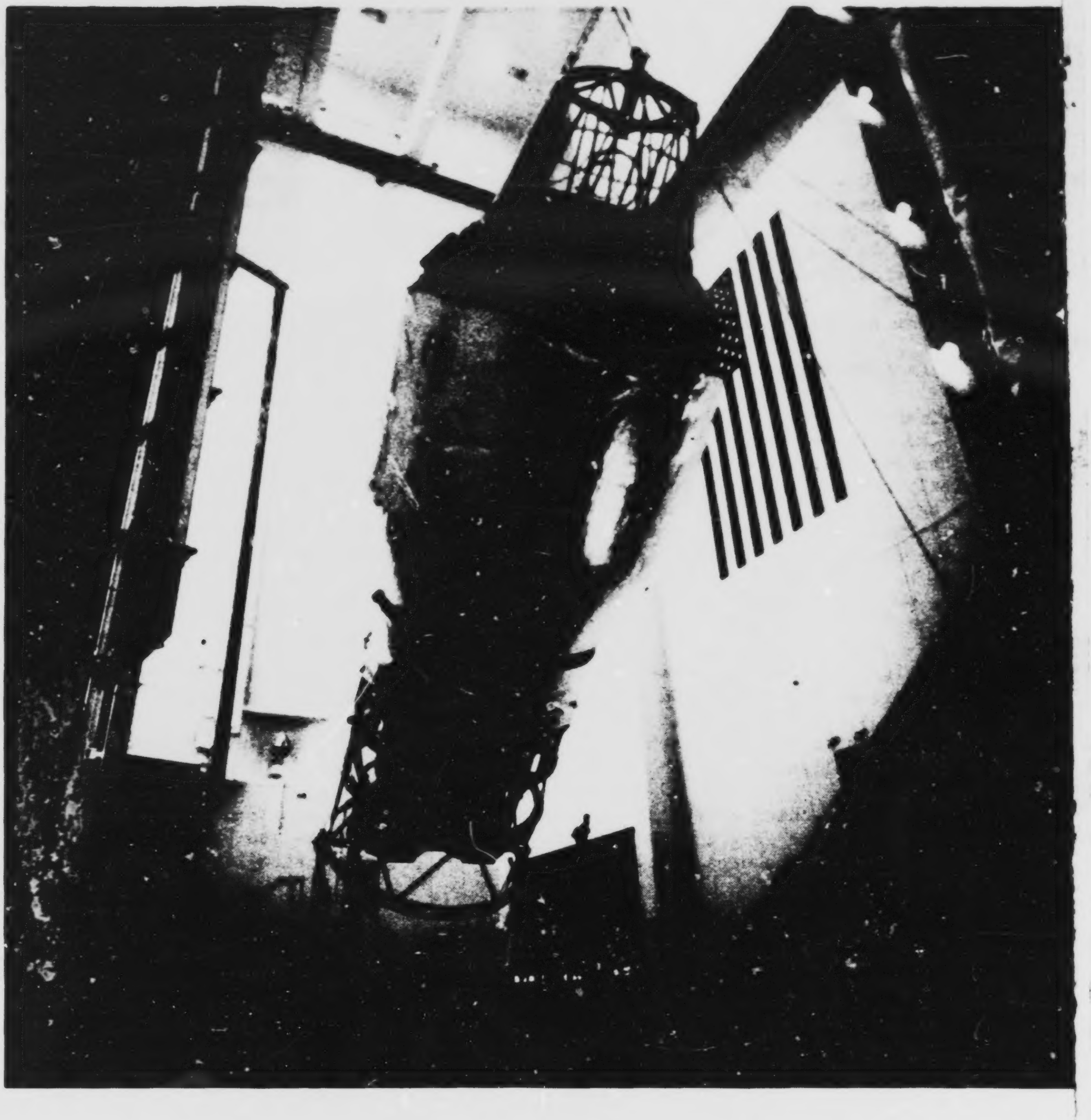

Figure 2-1. Shuttle/Centaur

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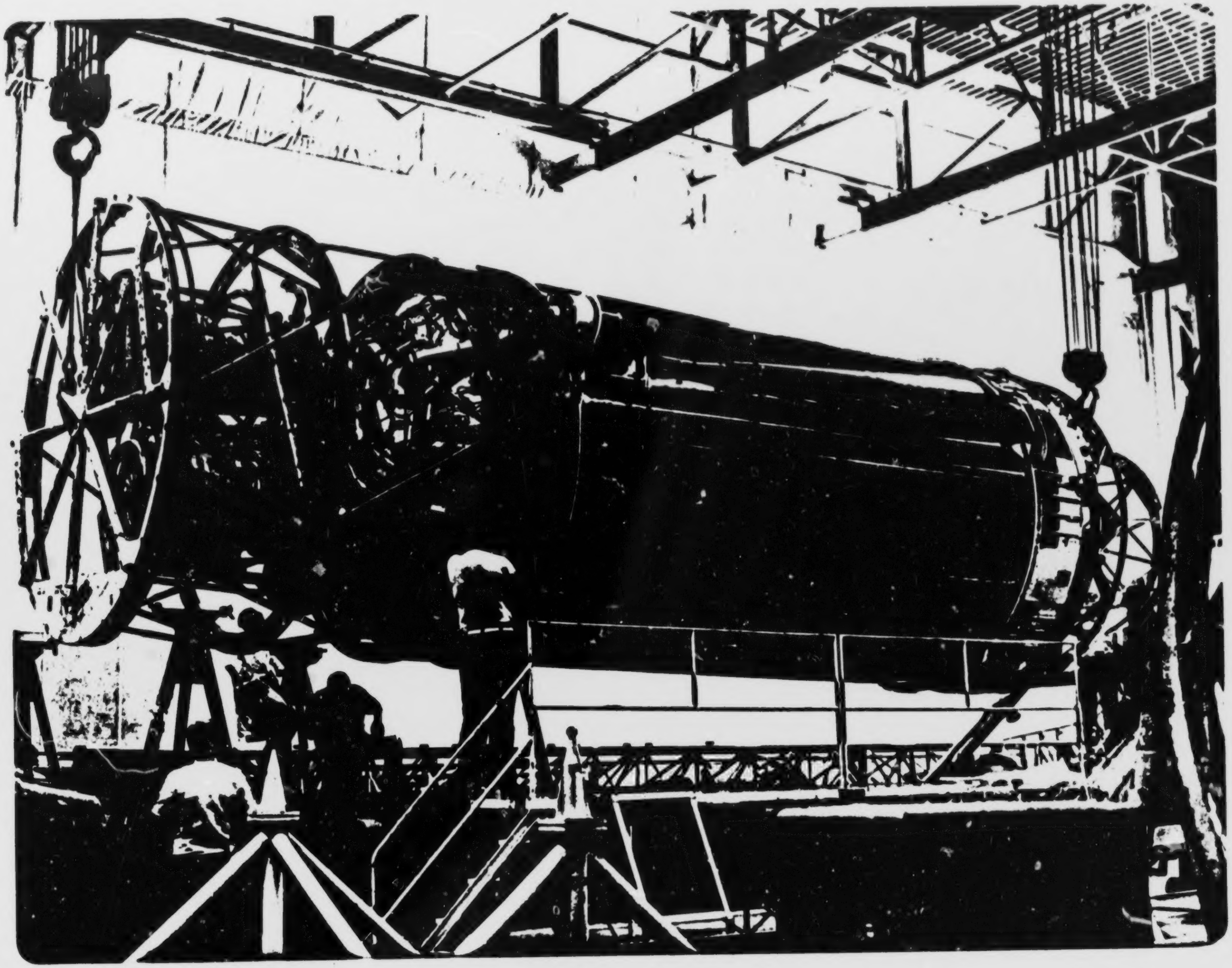

Figure 2-2. ATLAS/Centaur

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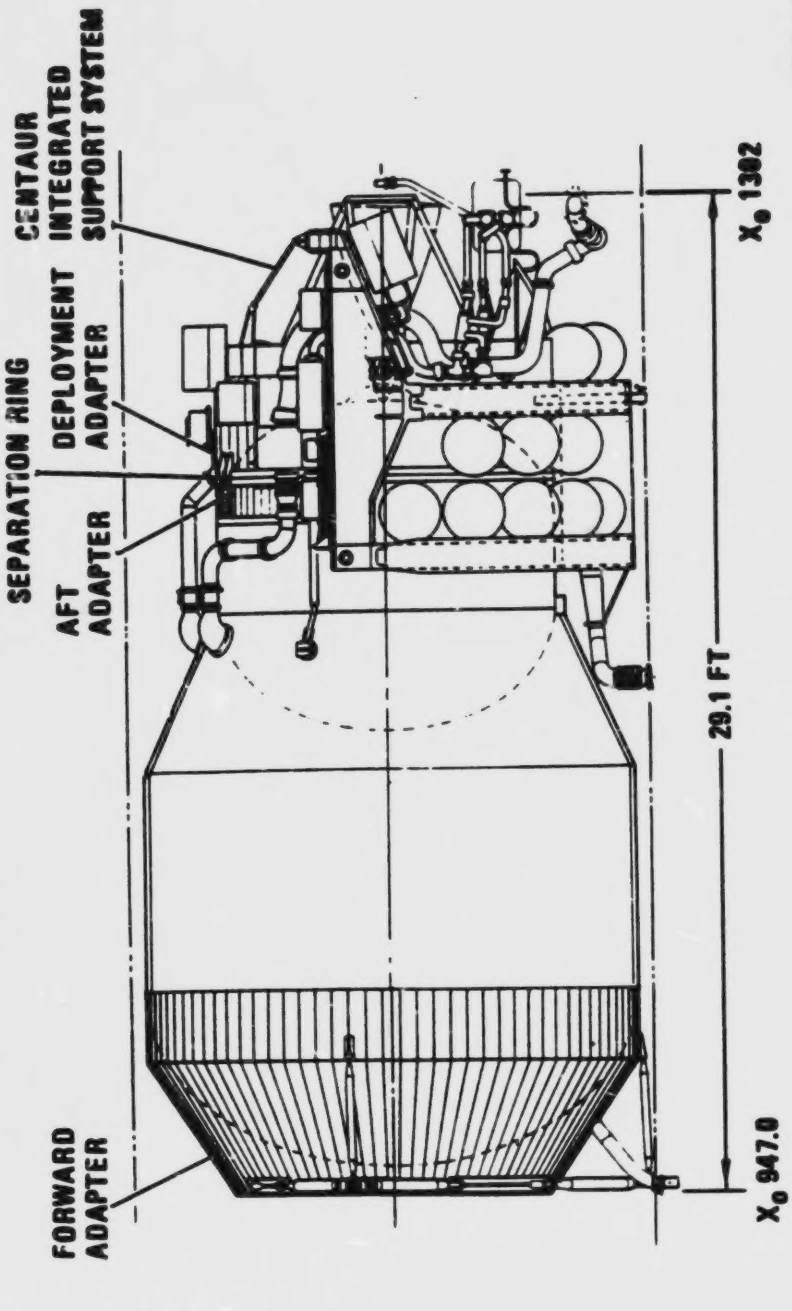

Figure 2-3. Shuttle/Centaur G-Prime and CISS (Reference)

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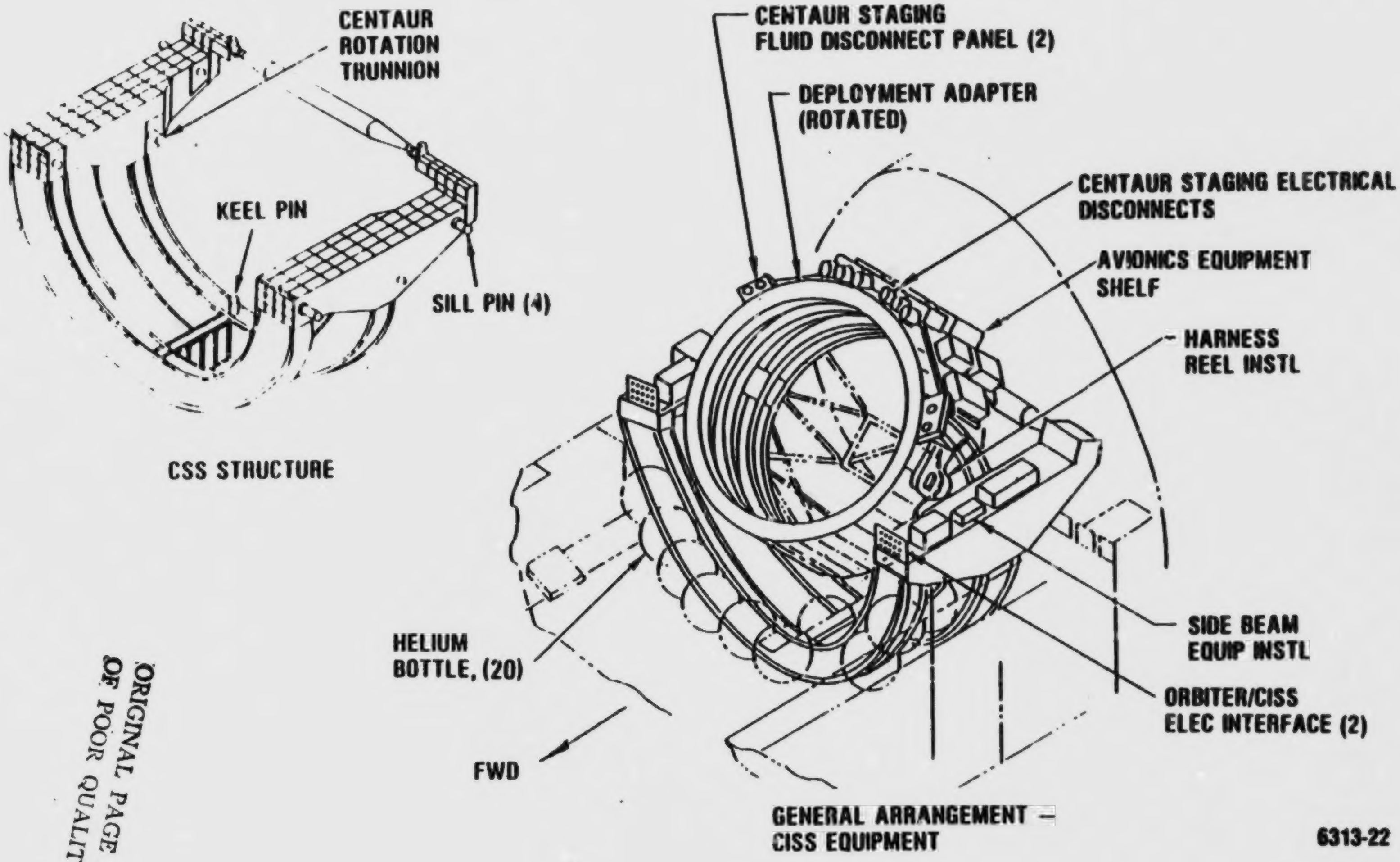

Figure 2-4. CISS

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for the proposed OTV configurations. The Atlas/Centaur vehicle processing is basically a manual operation. However, both versions are fully automated during flight.

The actual processing scenarios and facilities are also quite different for both vehicles. While the Atlas/Centaur is processed at one facility for checkout, payload mating and launch, the Shuttle/Centaur was processed at several facilities. Figure 2-5 shows how the Shuttle/Centaur is moved between the various facilities at ELS during ground processing. As a comparison, the moves between facilities in the Shuttle program double the lifting or handling operations versus an Atlas/Centaur stage. Because of the possibility of damage during lifting or handling, these operations tend to require large crews.

The point of coordinated operations at vertical processing facility (VPF) and Complex 39 (joint use facilities) is that besides having to coordinate with more activities for your own cargo, outside activities may affect your operation more easily than at a dedicated facility. For example, another cargo may be in the other VPF cell, requiring safety constraints, stopping Shuttle/Centaur operations, or requiring Orbiter interface verifications at the same time. Lastly, when moved to joint use facilities, managing integrated operations become more difficult because there are more parties involved.

The Shuttle/Centaur data reflects only the contractor efforts while in the VPF and Complex 39.

The added processing complexities for Shuttle/Centaur are noted here to show some of the differences from Atlas/Centaur processing and why the Atlas/Centaur data has been almost completely replaced by the Shuttle/Centaur data base as the foundation for assessing OTV operations.

2.2 SHUTTLE/CENTAUR PROCESSING DATA BASE

The Shuttle/Centaur data is based on the actual experience of processing the vehicle and CISS through Hangar J, Complex 36A, the VPF, and partial integration with Complex 39. The vehicle and CISS were received and inspected in Hangar J before going to Complex 36A for some assembly, subsystem testing, terminal countdown demonstrations, and hydrazine loading. The Centaur was then integrated with the development test module (a spacecraft simulator) and tested for Shuttle integration, while the Galileo spacecraft was integrated and received spacecraft-peculiar tests. At Complex 39, the Centaur ground support equipment (GSE) was installed and checked. The GSE included skids containing fluid and pneumatic plumbing and control equipment and fixed service equipment, which provides the Complex 36 to Complex 39 interface to allow remote monitor and control of the operations at Complex 39. Cold-flow tests through the skids up to the Orbiter interface were accomplished. Thus, all operations up to the point of installing the Shuttle/Centaur in the Orbiter were completed and provide the actual experience data bases. Planning was provided for Centaur and Orbiter integration and the launch confidence test.

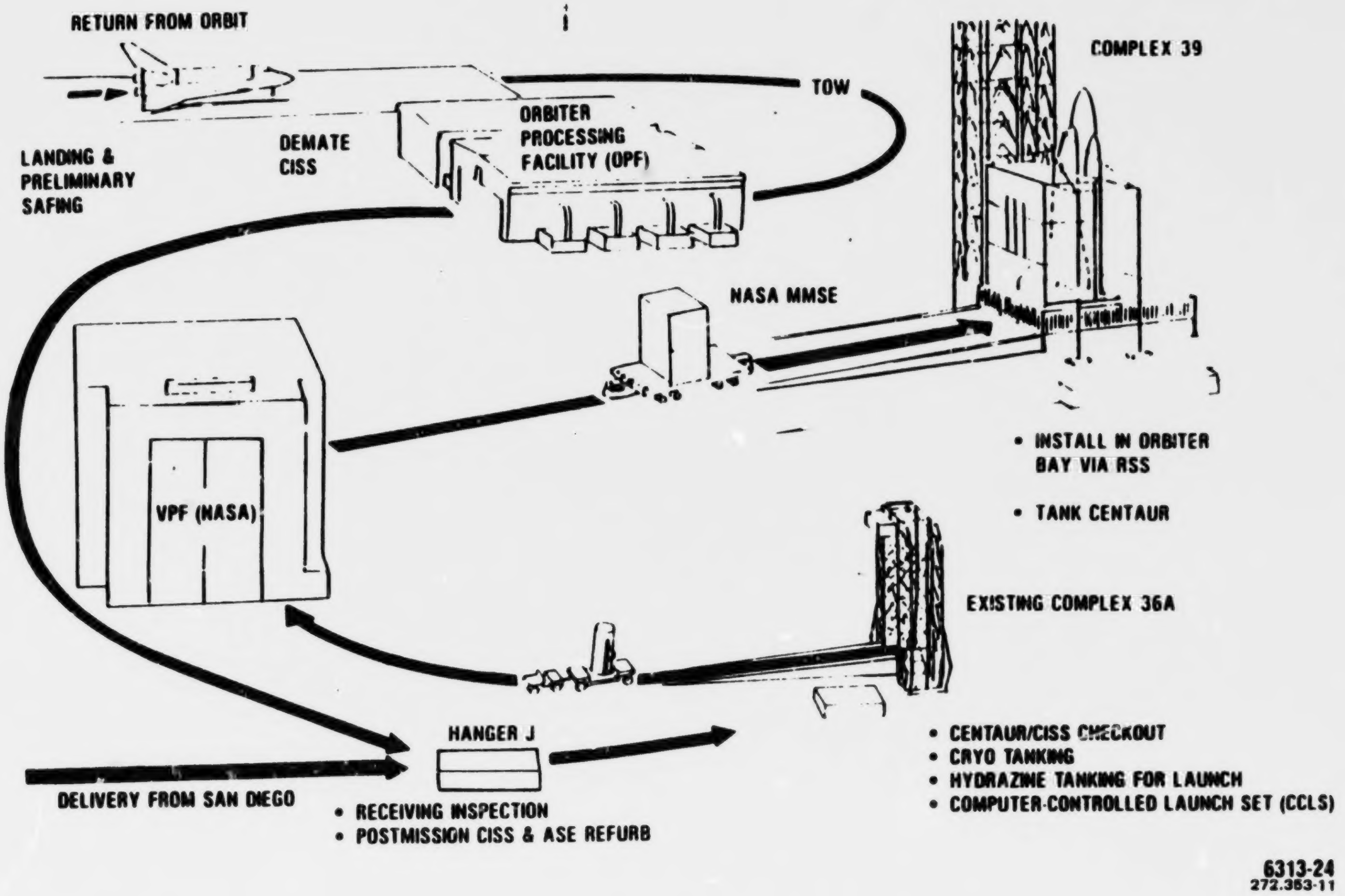

Figure 2-5. Centaur G-Prime Ground Operations at ELS

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The Shuttle/Centaur data base that transfers this hands-on cryogenic vehicle experience to OTV operations, contains functional flows, timelines, crew definitions, manpower loadings and procedures. This data is stored on computer discs to allow quick access and manipulation of the data during the analysis.

The Shuttle/Centaur processing Level 2 functional flow diagram is presented in Figure 2-6. It shows the major tasks required to process the vehicle and CISS through the various facilities. The associated timeline is shown in Figure 2-7. The data provides detailed information down to Level 3 and with the procedures listed at that level it goes even further into the detailed tasks. A synopsis of all the referenced procedures was also available during the analysis. Table 2-1 provides an example of the Shuttle/Centaur test procedures synopsis. The table contains the procedure number, title, Shuttle/Centaur task number where it is used, and a brief description of the procedure contents. The manloading information is shown in Table 2-2, which ties most of the previous data elements together. It provides the task number down to Level 3, task description, procedure number, personnel required, activity location, dicipline of personnel involved (team), start date, task time and task manhours.

This data base is used throughout the OTV operations analysis to determine realistic assessments for OTV processing.

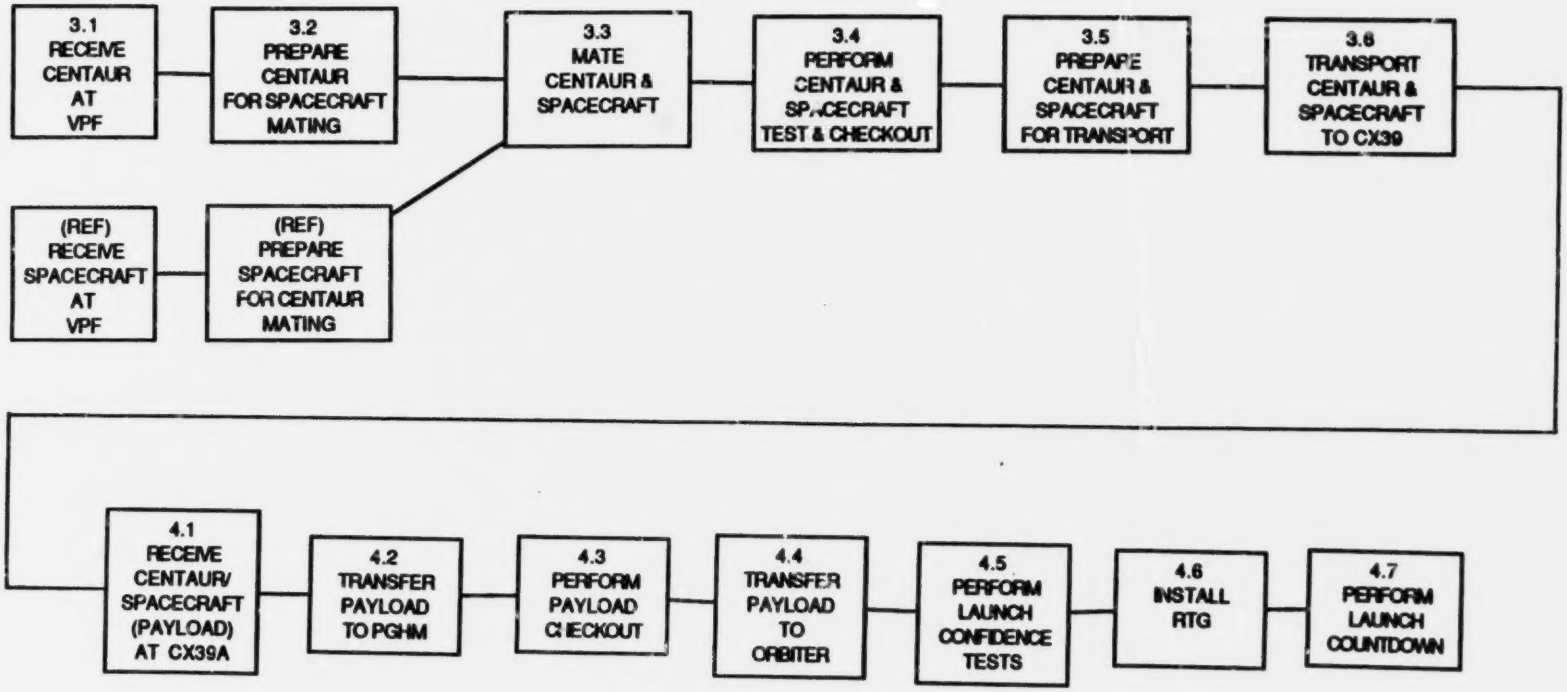
3.1 RECEIVE CENTAUR AT VPF
3.2 PREPARE CENTAUR FOR SPACECRAFT MATING
(REF) RECEIVE SPACECRAFT AT VPF
(REF) PREPARE SPACECRAFT FOR CENTAUR MATING
3.3 MATE CENTAUR & SPACECRAFT
3.4 PERFORM CENTAUR & SPACECRAFT TEST & CHECKOUT
3.5 PREPARE CENTAUR & SPACECRAFT FOR TRANSPORT
3.6 TRANSPORT CENTAUR & SPACECRAFT TO CX39
4.1 RECEIVE CENTAUR/ SPACECRAFT (PAYLOAD) AT CX39A
4.2 TRANSFER PAYLOAD TO PGHM
4.3 PERFORM PAYLOAD CHECKOUT
4.4 TRANSFER PAYLOAD TO ORBITER
4.5 PERFORM LAUNCH CONFIDENCE TESTS
4.6 INSTALL RTG
4.7 PERFORM LAUNCH COUNTDOWN

Figure 2-6. Shuttle/Centaur Processing Task Flow (Example)

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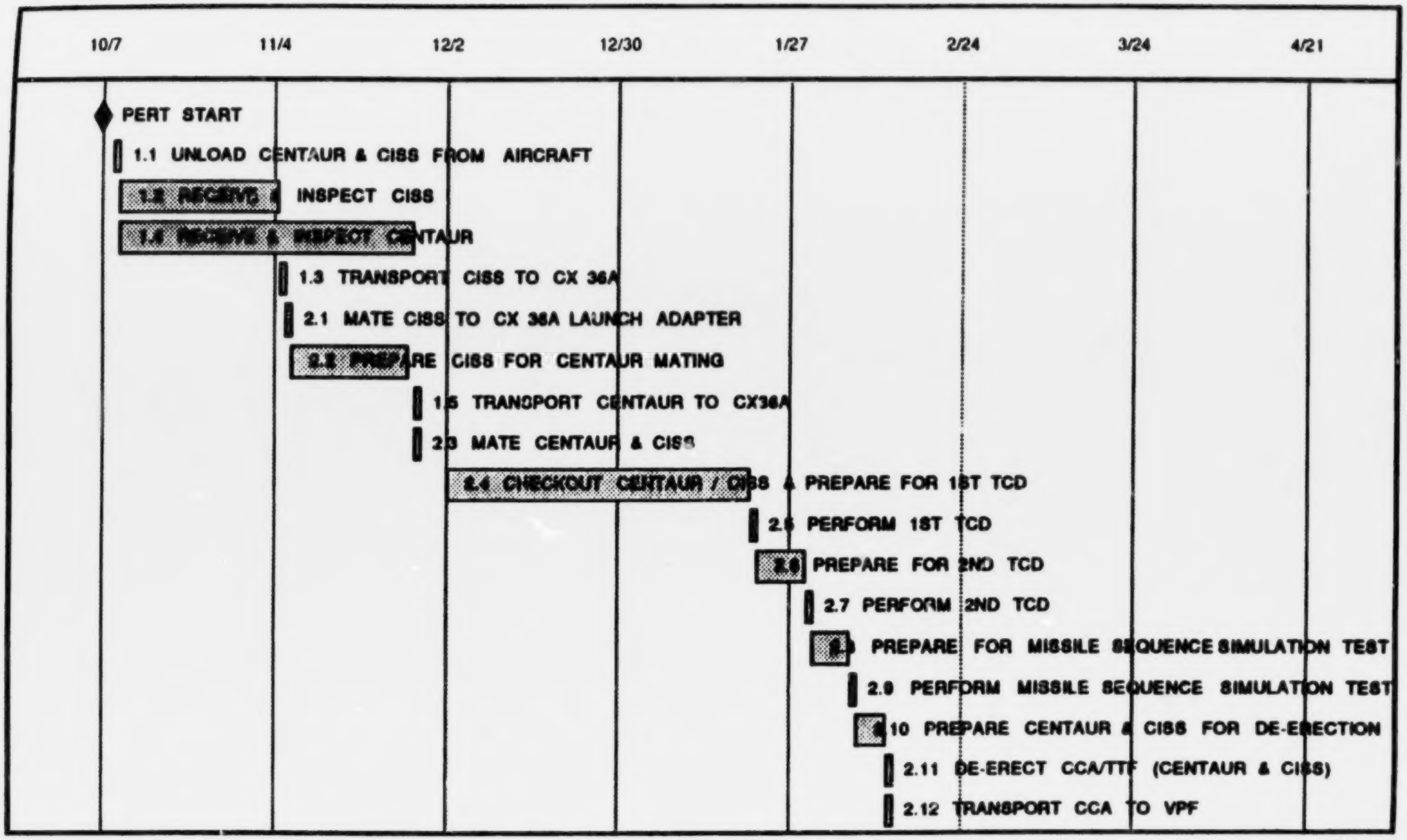

Figure 2-7. Shuttle/Centaur Processing Timeline (Example

PNEU-9006 65-30009 CISS PAVCS SYSTEM CHECKOUT	1.2.6	THIS PROCEDURE PERFORMS INTERNAL AND EXTERNAL LEAK CHECKS OF ALL COMPONENTS IN THE CISS PAVCS SYSTEM, VERIFIES COMPONENT AND SYSTEM FLOWRATES AND PRESSURE READINGS, AND PERFORMS AN OPERATIONAL TEST OF THE SYSTEM. THIS PROCEDURE IS INTENDED FOR USE AT CX36A ONLY.
PNEU-9007 65-30075 CISS VENT SYSTEM CHECKOUT	1.2.5	THIS PROCEDURE DEFINES THE METHODS USED TO TEST AND VALIDATE THE CISS VENT SYSTEMS. THIS PROCEDURE ACCOMPLISHES THE FOLLOWING: CISS VENT VALVES LOAD VERIFICATION TEST, CISS GH2 VENT VALVES LEAK AND FUNCTIONAL TEST, AND CISS GO2 VENT VALVES LEAK AND FUNCTIONAL TEST. THIS PROCEDURE IS INTENDED FOR USE AT COMPLEX 36A ONLY.
PNEU-9008 65-30016 CENTAUR APCS/CCVAPS SYSTEM FUNCTIONAL CHECKS	2.4.8	THIS PROCEDURE DEFINES THE METHODS USED TO TEST AND VALIDATE THE CENTAUR APCS/CCVAPS TRANSDUCERS AND TANK PRESSURE TRANSDUCERS FOR PERFORMING AND END-TO-END CALIBRATION.
PNEU-9009 65-30014 CENTAUR PRESSURIZATION SYSTEM FUNCTIONAL CHECKS	2.4.6	THIS PROCEDURE DEFINES THE METHODS USED TO TEST AND VALIDATE THE CENTAUR PRESSURIZATION SYSTEM BY ACCOMPLISHING THE FOLLOWING: CENTAUR PRESSURIZATION LOAD VERIFICATION TEST, CENTAUR PRESSURIZATION VALVES INTERNAL LEAK CHECK, AND CENTAUR PRESSURIZATION VALVES FLOW TEST. THIS PROCEDURE IS INTENDED FOR USE ON CX36A ONLY.
PNEU-9010 65-30008 CENTAUR PAVCS SYSTEM CHECKOUT	2.4.4	THIS PROCEDURE PERFORMS INTERNAL AND EXTERNAL LEAK CHECKS OF ALL COMPONENTS IN THE CENTAUR PAVCS SYSTEM, VERIFIES COMPONENT AND SYSTEM FLOW RATES AND PRESSURE READINGS, AND PERFORMS AN OPERATIONAL TEST OF THE SYSTEM. THIS PROCEDURE IS INTENDED FOR USE AT CX36A ONLY.
PNEU-9011 65-30091 CENTAUR VENT SYSTEM CHECKOUT	1.4.9 2.4.5	THIS PROCEDURE DEFINES THE METHODS USED TO TEST AND VALIDATE THE CENTAUR VENT SYSTEMS. THIS PROCEDURE ACCOMPLISHES THE FOLLOWING: CENTAUR VENT VALVES LOAD VERIFICATION TEST, CENTAUR GH2 VENT VALVES LEAK AND FUNCTIONAL, AND CENTAUR GO2 VENT VALVES LEAK AND FUNCTIONALY. THIS PROCEDURE IS INTENDED FOR USE AT COMPLEX 36A ONLY.

Table 2-1. Shuttle/Centaur Test Procedures Synopsis

TASK NUMBER	TASK DESCRIPTION	PROCEDURES	PERSONNEL REQUIRED					LOCATION				TEAM	START DATE	TASK TIME	TOTAL MANHOURS
			ENG	MECH	TECH	INSP	PWR	J	36A	VPF	39A		Y/MM/DD	(HRS)	(HRS)
1.1	UNLOAD CENT/CISS FROM ACFT		2	4	1	1		---SKID STRIP--				STR	5/10/09	8	64
1.1	UNLOAD CENT/CISS FROM ACFT		1	2		1		---SKID STRIP--				PNEU	5/10/09	8	32
1.2(REF)	RCV & INSP CISS							X					5/10/10		0
1.2.1	CISS PREPOWER I/F TEST	NET-9005	1		1	1		X				ELEC	5/10/10	24	72
1.2.2	CISS STD TURN-ON PROFILE	NET-9007	2		2	2		X				ELEC	5/10/15	8	48
1.2.2	CISS STD TURN-ON PROFILE	NET-9007	2					X				AV	5/10/15	8	16
1.2.2	CISS STD TURN-ON PROFILE	NET-9007	2					X				INSTR	5/10/15	8	16
1.2.2	CISS STD TURN-ON PROFILE	NET-9007					20	X				PWR	5/10/15	(8)	0
1.2.3	CISS AV SUBSYS FCTN CO	NET-9000	1		2	1		X				ELEC	5/10/16	40	160
1.2.3	CISS AV SUBSYS FCTN CO	NET-9000	2		1			X				AV	5/10/16	40	120
1.2.3	CISS AV SUBSYS FCTN CO	NET-9000					20	X				PWR	5/10/16	(8)+ 32	640
1.2.4	CISS PRESS SYS FCTN CO	PNEU-9005	2	3		1		X				PNEU	5/10/23	40	240
1.2.4	CISS PRESS SYS FCTN CO	PNEU-9005					19	X				PWR	5/10/23	40	760
1.2.5	CISS VENT SYS CO	PNEU-9007	2	3		1		X				PNEU	5/10/30	16	96
1.2.5	CISS VENT SYS CO	PNEU-9007					19	X				PWR	5/10/30	16	304
1.2.6	CISS PAVCS FCTN CO	PNEU-9006	2	3		1		X				PNEU	5/10/24	32	192
1.2.6	CISS PAVCS FCTN CO	PNEU-9006					19	X				PWR	5/10/24	(32)	0
1.2.7	CISS PURGE SYS CHKS	PNEU-9016	2	4		2		X				PNEU	5/10/30	8	64
1.2.7	CISS PURGE SYS CHKS	PNEU-9016					19	X				PWR	5/10/30	(8)	0
1.2.8	CISS MECH RCV & INSP	MECH-9001				3		X				STR	5/10/10	40	120
1.2.9	CISS ELEC RCV & INSP	NET-9001				3		X				ELEC	5/10/10	40	120
1.2.10	CISS INSTRU RCV & INSP	TLM-9003	1		1	1		X				INSTR	5/10/10	40	120
1.2.11	CISS PWR-OFF XDCR RING-OUT	TLM-9005	1		2	1		X				INSTR	5/10/10	16	64
1.2.12	CISS PWR-ON XDCR RING-OUT	TLM-9005	3		3	2		X				INSTR	5/10/14	24	192
1.2.12	CISS PWR-ON XDCR RING-OUT	TLM-9005					18	X				PWR	5/10/14	(24)	0
1.2.13	CISS PNEU SYS RCVG PREPS	PNEU-9019	1	2		1		X				PNEU	5/10/10	32	128

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Table 2-2. Shuttle/Centaur ELS Manloading

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SECTION 3

OTV GROUNDS OPERATIONS ANALYSIS

The OTV ground operations derived from the Shuttle/Centaur processing data (through functional analysis), trade studies, and the resultant recommendations are discussed in this section. The analyses are conducted on five of the OTV configurations previously mentioned in Section 1.3 which includes the following:

a. Reusable GBOTV - Cargo Bay

b. Expendable GBOTV

c. Reusable GBOTV - Aft Cargo Carrier

d. SBOTV

e. UCV OTV

The analysis evaluates the functional differences between these OTV configurations and determines processing requirements, functional flows, timelines, manpower requirements, and operational costs for all configurations.

The approach for doing the functional analysis starts with assessing the Shuttle/Centaur database and identifying task functions that correlate with each OTV configuration. Functional processing requirements are then generated based on the correlation data. OTV-specific tasks and some additional turnaround tasks are added to the requirements to provide inputs to the "OTV Turnaround Operations Requirements Document" (GDSS-ASP-86-100). Functional flows are constructed, based on the correlation data and requirements, which provide inputs to the task analysis worksheets manloading data In turn, the task duration data from the task analysis worksheets is fed back into the functional flows to produce the timelines.

The Macintosh computer with MAC project software is used to generate the functional flows and timelines. An IBM computer with Lotus 123 software is used for the task analysis worksheet manloading data.

It should be noted that all factory processing functions that were part of the Shuttle/Centaur data are identified and deleted from the analysis because they are inappropriate for efficient launch site processing and they do not mesh with the study ground rules. This amounts to 4,688 manhours, which are in the Shuttle/Centaur database that will not show up in the OTV ground processing data.

In doing the analysis, four options are considered as shown in Figure 3-1. This includes two facility options and two level of automation options. One facility option is a Shuttle/Centaur-type facility where the vehicle is processed through Hangar J, Complex 36A, the VPF, and Complex 39. The other facility is a new integrated facility which would combine Hangar J, Complex 36A, and the VPF functions into one building, which would be similar to the

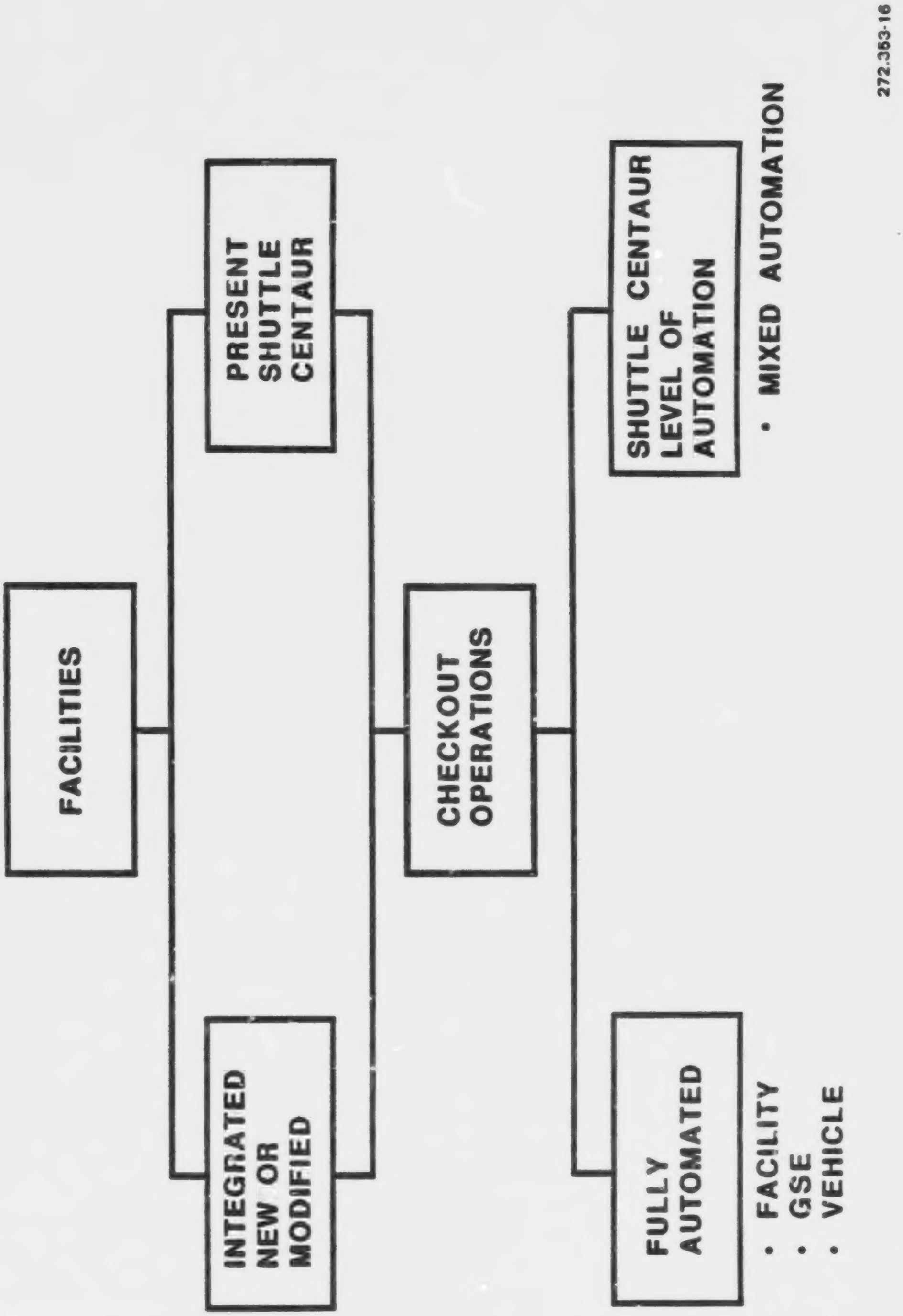


Figure 3-1. Ground Operations Trade Tree

existing VPF. The integrated facility would be designed from the inception to make ground operations more efficient (e.g., a higher level of facility automation, easier handling and access features).

The second set of options considers the level of automation for checkout of the OTV.

First, we use the Shuttle/Centaur level of automation which is characterized as mixed, meaning that some operations such as avionics checkout are fully automated, while others such as pneumatics are not nearly as automated. The second option is full automation, meaning that we assume that ground processing is automated as much as possible thereby offering savings not only in ground operations task time, but also in crew size.

The four options are only assessed in the reusable GBOTV cargo bay configuration. The other configurations are assessed with regard to the two extreme options [i.e., Shuttle/Centaur-type facility with Shuttle/Centaur level of automation and integrated processing facility (IPF) with full automation].

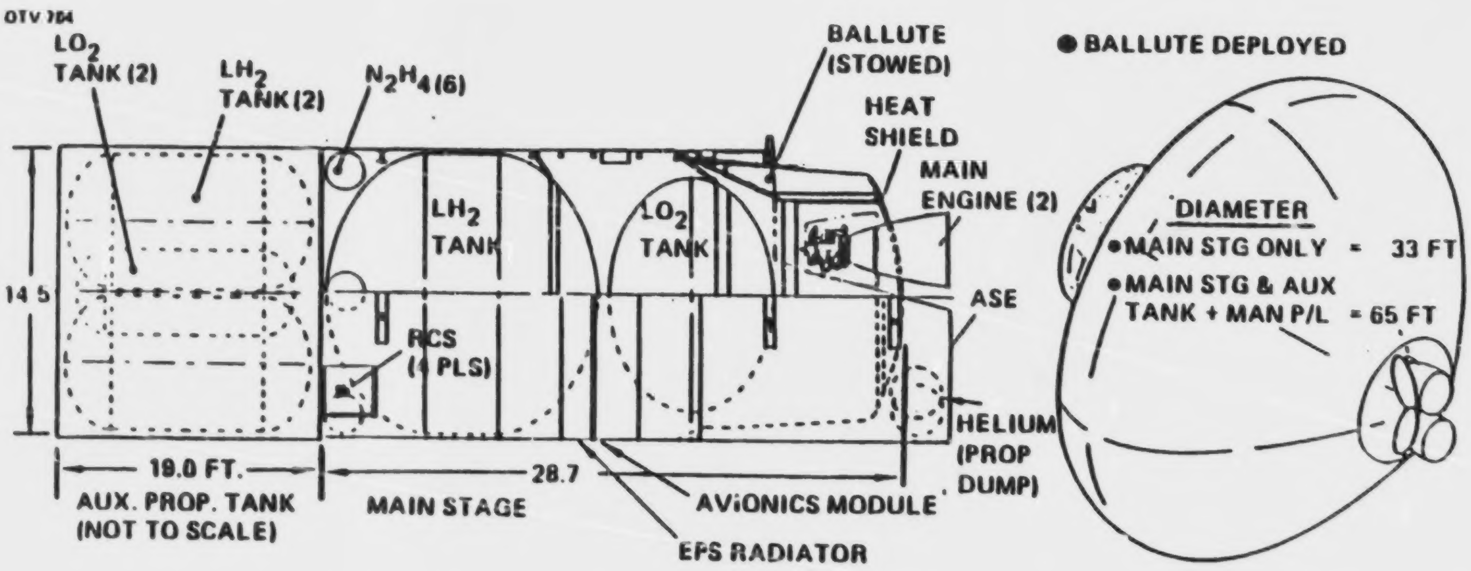
The first OTV configuration in the analysis is the reusable cargo bay vehicle which is similar to the Shuttle/Centaur in complexity and operational scenario.

3.1 REUSABLE CARGO BAY (BALLUTE) GBOTV

The OTV assessed in this section is a Boeing concept and is similar to the Shuttle/Centaur, except for auxiliary tanking and ballute-type aerobrake system.

3.1.1 CARGO BAY GBOTV DEFINITION. The vehicle concept developed by Boeing during the Phase A OTV definition studies is shown in Figure 3-2. This concept uses an expendable ballute for an aeroassist device, which is assembled on the vehicle shortly after return from a mission during turnaround operations. The vehicle concept has a payload carrying complexity which has not been considered in this analysis. Some payloads cannot be carried in the cargo bay with the OTV because the total liftoff weight exceeds the Shuttle launch capability, especially in the case where auxiliary tanks are used, when volume is also a limitation. This means that two Shuttle flights are required to carry the OTV and payload to orbit. This analysis only considers the case where the vehicle is mated with the payload on the ground, integrated into the Orbiter cargo bay, and carried to orbit in one Shuttle flight.

3.1.2 CARGO BAY GBOTV PROCESSING REQUIREMENTS. OTV correlation with the Shuttle/Centaur data is assessed and defined as shown in Table 3-1. The task analysis/manloading worksheet (presented in Table 2-2) is modified to show only the Shuttle/Centaur processing task number, task description, and procedures with a column added for correlation identification. The numbers in this column are eventually deleted and the remaining contents are merged with added tasks to form the final manloading database. From this data, requirements are established and complied in the requirements document (GDSS-ASP-86-100). This data is also used in modifying the functional flows to reflect OTV operational tasks for both initial and turnaround processing. The correlation data example is shown here for clarification on this particular OTV configuration and will not be repeated in other sections.



UNIQUE FEATURES

- BALLUTE–SAME AS SB OTV
- HEAT SHIELD–SAME AS SB OTV
- MAIN STAGE
  - USED ON ALL FLIGHTS
- AUX. PROP. TANK
  - USED ON 36 FLIGHTS
- MAIN STAGE ATTACHED TO AUX. TANK/PAYLOAD AT STATION

WEIGHT SUMMARY (LBS)

	10K NET DELIV	MAN SORTIE (7.5K)	
	MAIN	MAIN	AUX
● DRY	7995	9987	3401
● MAIN PROP	47698	47698	33722
● OTHER FLUIDS	768	1700	---
● STG STARTBURN	56461	59385	37123
● PAYLOAD (NET)	10000	---	7500
● PAYLOAD RACK	1000	---	---
● ASE	6390	6390	6390
LIFTOFF	73851	65775	51013

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Figure 3-2. Ballute-Braked GBOTV

TASK NUMBER	TASK DESCRIPTION	PROCEDURES	GBOTV USE Y/N	COMMENTS/RATIONALE
2.4.1DEL			N	DELETED
2.4.2DEL			N	DELETED
2.4.3	AV SUBSYS FCTN CO	NET-9000	Y	
2.4.4	CENT PAVCS SYS CO	PNEU-9010	Y	
2.4.5	CENT VENT SYS FNTC CO	PNEU-9011	Y	
2.4.6	CENT PRESS SYS FNTC CO	PNEU-9009	Y	
2.4.7	CENT & CISS HE STOR PRESS	PNEU-9004	Y	
2.4.8	CENT CCVAPS/APCS CHKS	PNEU-9008	N	
2.4.9	VERFY CENT/CISS PNEU RDNS	PNEU-9013	Y	
2.4.10	CENT TO CISS FL LINE CHKS		Y	
2.4.11	N2H4 SYS THR LOOP PRESS	N2H4-9004	Y	FACTORY PROCESSING
2.4.12	N2H4 SYS LEAK & FNTC TEST	N2H4-9002	Y	FACTORY PROCESSING
2.4.13	CENT/CISS PRESS CHG OVER	PNEU-9012	N	
2.4.14	INSTL PROP DUCT HEAT SHLDS		Y	FACTORY PROCESSING
2.4.15	APPLY FOAM PROP SYS XDCR		Y	FACTORY PROCESSING
2.4.16	INSTL PROP HEAT SHIELD		Y	FACTORY PROCESSING
2.4.17	VRFY PROP & HYD SYS READY	PROP-9004	Y	
2.4.18	CRYO FLG BOLT TRQ CHKS	PROP-9002	Y	
2.4.19	MAIN ENG LEAK CHKS	PROP-9003	Y	FACTORY PROCESSING
2.4.20	INSTL ENG SUPPORTS		N	
2.4.21	RMV ENGINE SUPPORTS		N	
2.4.22	HYD SYS LEAK & FNCT TEST	HYD-9001	Y	FACTORY PROCESSING
2.4.23	HYD END TO END TEST	HYD-9003	Y	FACTORY PROCESSING
2.4.24DEL			N	DELETED
2.4.25	RCV/INSP INSTRU & RF EQUIP	TLM-9002	Y	
2.4.26	CENT PUMP SPEED CO	TLM-9006	Y	FACTORY PROCESSING
2.4.27	RF SYS CO	RF-9000	Y	
2.4.28	CENT & CISS HE STOR PRESS	PNEU-9004	N	
2.4.28	CENT & CISS HE STOR PRESS	PNEU-9004	N	
2.4.29	CENT PWR-OFF XDCR RING-OUT	TLM-9000	Y	FACTORY PROCESSING
2.4.30	CENT PWR-ON XDCR RING-OUT	TLM-9000	Y	FACTORY PROCESSING

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Table 3-1. Shuttle/Centaur to GBOTV - Cargo Bay/GBOTV Expendable Processing Correlations

3.1.3 FUNCTIONAL FLOWS (LEVEL 2 AND LEVEL 3). The Shuttle/Centaur functional flow diagrams are modified based on the correlation data and OTV-specific and turnaround task data requirements. Functional flows are generated to support each trade study option. However, only the facility options reveal any differences, because the level of automation does not add or delete a task, only the way the task is implemented.

Figure 3-3 presents the Level 2 functional flow diagram of the cargo bay reusable GBOTV, which is processed using Shuttle/Centaur type facilities. The flow includes factory processing, initial processing, and turnaround operations. Factory processing is shown here, because the baseline Shuttle/Centaur data included some of these functions. The factory processing functions have been identified and are deleted from the operations analysis.

The initial processing of the vehicle begins by unloading the OTV from the delivery aircraft (2.1) and ends when the vehicle is launched (4.4).

Turnaround operations include all of the initial processing functions except 2.1, and add functions 5.0 through 8.0 to the flow. During turnaround operations, the ASE and vehicle will be checked out only to the extent necessary. The amount of checkout required will be determined by flight data analysis, and maintenance/reconfiguration performed. An asterisk in front of the functional number denotes those functions that would be affected by checkout requirements.

The Level 2 functional flow diagram of the cargo bay reusable GBOTV processed in an IPF is shown in Figure 3-4. The IPF scenario reduces the number of moves between facilities which eliminates tasks 2.4, 2.7, 3.6, and 3.7 from the flow shown in Figure 3-3. There are other differences that will show up in the timelines and manloading analysis.

3.1.4 MANPOWER ASSESSMENTS AND TIMELINES. Task analysis worksheets for the cargo bay reusable GBOTV are manipulated to reflect the input data from the correlation effort and the functional flows. Worksheets are prepared for both the initial and turnaround ground processing operations for each of the four facility/automation options. That means eight task analysis worksheets exist for this vehicle configuration. Table 3-2 gives a worksheet example of one of the options for turnaround processing. This worksheet, which is typical, goes down to Level 3 and has 124 working tasks, 286 entries on 9 pages.

The worksheet identifies the OTV task number and lists the corresponding Shuttle/Centaur task number from that data base to provide adequate traceability. New OTV tasks register a blank in the Shuttle/Centaur task number column.

The worksheet also contains task descriptions, procedures, personnel required, activity location, discipline of personnel involved (team), task time, and task manhours. Manhours for optional turnaround tasks are shown in the last column. These optional tasks are not required if the vehicle returns from a mission without faults and does not need preventive maintenance or reconfiguration.

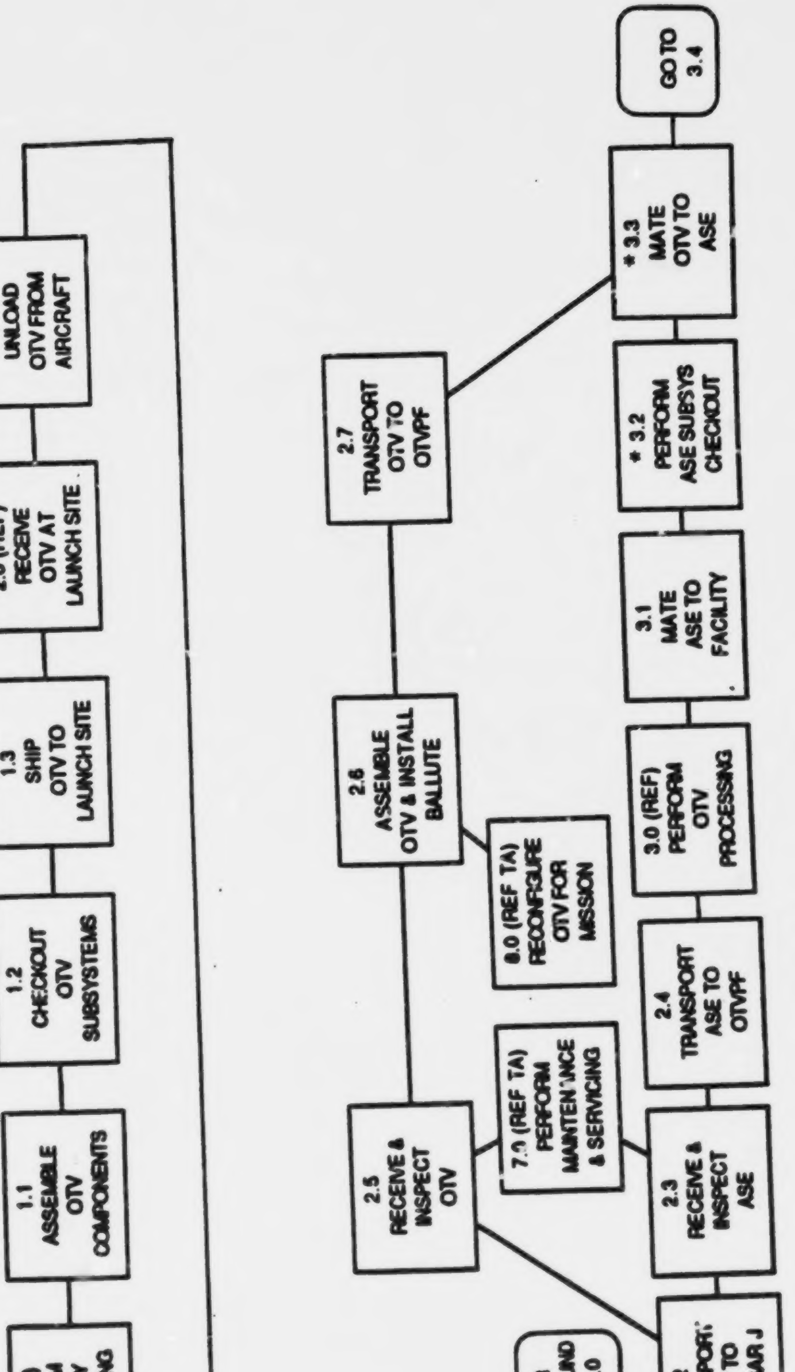
1.0 (REF) PERFORM FACTORY PROCESSING
1.1 ASSEMBLE OTV COMPONENTS
1.2 CHECKOUT OTV SUBSYSTEMS
1.3 SHIP OTV TO LAUNCH SITE
2.0 (REF) RECEIVE OTV AT LAUNCH SITE
2.1 UNLOAD OTV FROM AIRCRAFT
ENTER TURNAROUND FROM 8.0
2.2 TRANSPORT OTV TO HANGAR J
2.5 RECEIVE & INSPECT OTV
7.0 (REF TA) PERFORM MAINTENANCE & SERVICING
2.3 RECEIVE & INSPECT ASE
2.4 TRANSPORT ASE TO OTVPF
8.0 (REF TA) RECONFIGURE OTV FOR MISSION
2.6 ASSEMBLE OTV & INSTALL BALLUTE
3.0 (REF) PERFORM OTV PROCESSING
2.7 TRANSPORT OTV TO OTVPF
3.1 MATE ASE TO FACILITY
* 3.2 PERFORM ASE SUBSYS CHECKOUT
* 3.3 MATE OTV TO ASE
GO TO 3.4

Figure 3-3. Cargo Bay OTV Functional Flow: Shuttle/Centaur Type Facility

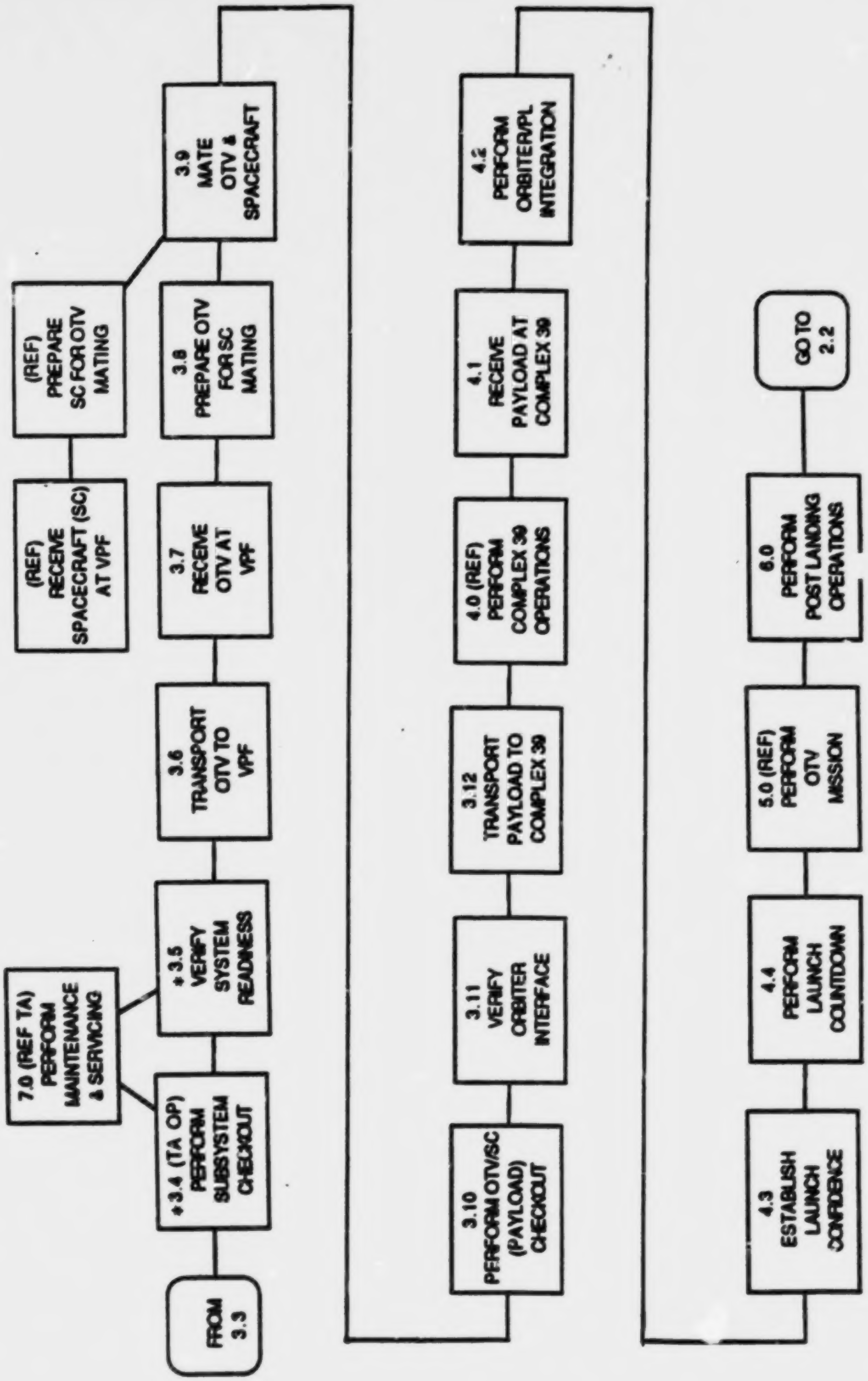
FROM 3.3
* 3.4 (TA OP) PERFORM SUBSYSTEM CHECKOUT
7.0 (REF TA) PERFORM MAINTENANCE & SERVICING
* 3.5 VERIFY SYSTEM READINESS
3.6 TRANSPORT OTV TO VPF
3.7 RECEIVE OTV AT VPF
(REF) RECEIVE SPACECRAFT (SC) AT VPF
(REF) PREPARE SC FOR OTV MATING
3.8 PREPARE OTV FOR SC MATING
3.9 MATE OTV & SPACECRAFT
3.10 PERFORM OTV/SC (PAYLOAD) CHECKOUT
3.11 VERIFY ORBITER INTERFACE
3.12 TRANSPORT PAYLOAD TO COMPLEX 39
4.0 (REF) PERFORM COMPLEX 39 OPERATIONS
4.1 RECEIVE PAYLOAD AT COMPLEX 39
4.2 PERFORM ORBITER/PL INTEGRATION
4.3 ESTABLISH LAUNCH CONFIDENCE
4.4 PERFORM LAUNCH COUNTDOWN
5.0 (REF) PERFORM OTV MISSION
6.0 PERFORM POST LANDING OPERATIONS
GO TO 2.2

Figure 3-3. Cargo Bay OTV Functional Flow: Shuttle/Centaur Type Facility, Contd

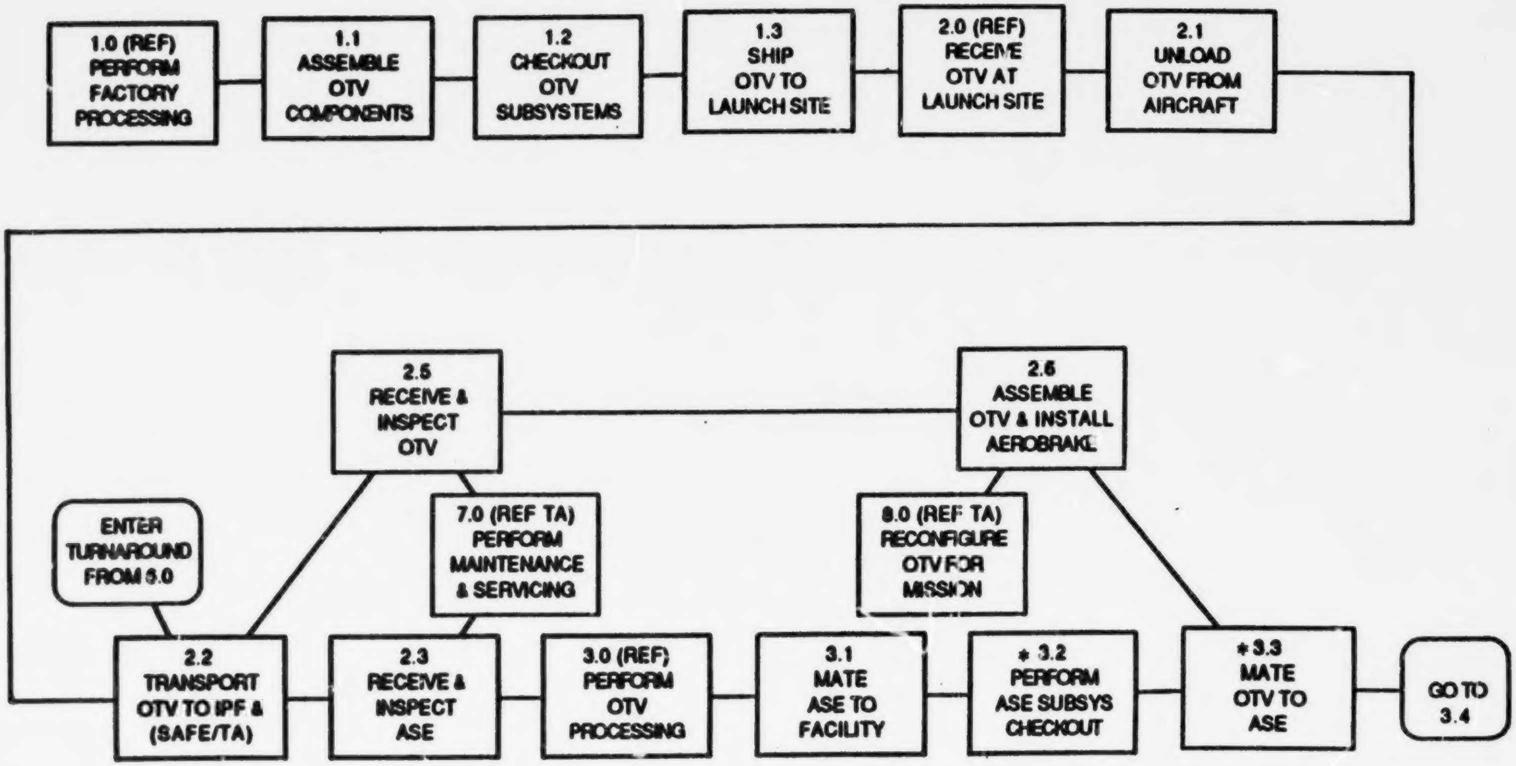
1.0 (REF) PERFORM FACTORY PROCESSING
1.1 ASSEMBLE OTV COMPONENTS
1.2 CHECKOUT OTV SUBSYSTEMS
1.3 SHIP OTV TO LAUNCH SITE
2.0 (REF) RECEIVE OTV AT LAUNCH SITE
2.1 UNLOAD OTV FROM AIRCRAFT
ENTER TURNAROUND FROM 6.0
2.2 TRANSPORT OTV TO IPF & (SAFE/TA)
2.5 RECEIVE & INSPECT OTV
7.0 (REF TA) PERFORM MAINTENANCE & SERVICING
2.3 RECEIVE & INSPECT ASE
3.0 (REF) PERFORM OTV PROCESSING
3.1 MATE ASE TO FACILITY
2.6 ASSEMBLE OTV & INSTALL AEROBRAKE
8.0 (REF TA) RECONFIGURE OTV FOR MISSION
* 3.2 PERFORM ASE SUBSYS CHECKOUT
* 3.3 MATE OTV TO ASE
GO TO 3.4

Figure 3-4. Cargo Bay OTV Functional Flow: IPF

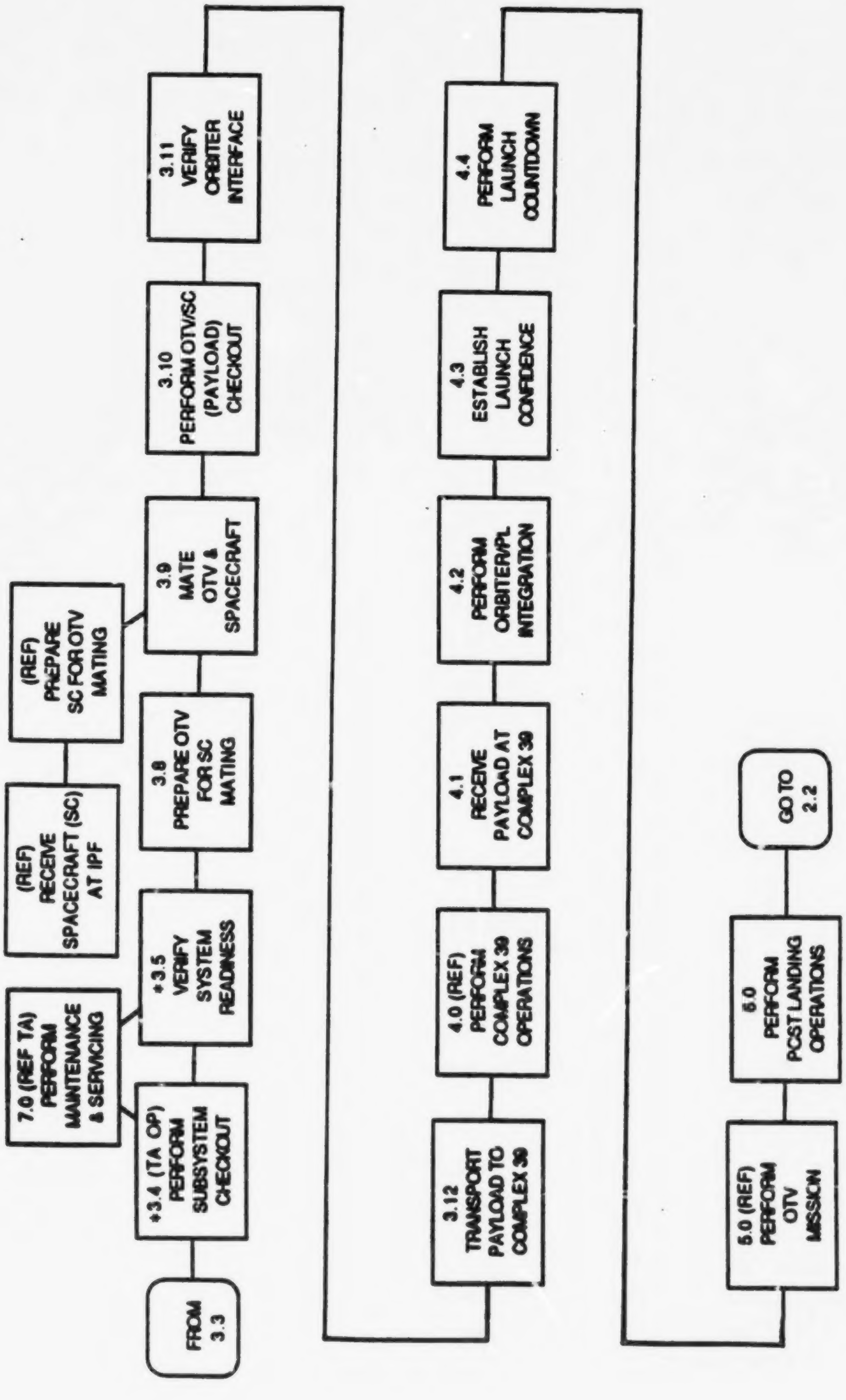
FROM 3.3
*3.4 (TA OP) PERFORM SUBSYSTEM CHECKOUT
7.0 (REF TA) PERFORM MAINTENANCE & SERVICING
*3.5 VERIFY SYSTEM READINESS
(REF) RECEIVE SPACECRAFT (SC) AT IPF
3.8 PREPARE OTV FOR SC MATING
(REF) PREPARE SC FOR OTV MATING
3.9 MATE OTV & SPACECRAFT
3.10 PERFORM OTV/SC (PAYLOAD) CHECKOUT
3.11 VERIFY ORBITER INTERFACE
3.12 TRANSPORT PAYLOAD TO COMPLEX 39
4.0 (REF) PERFORM COMPLEX 39 OPERATIONS
4.1 RECEIVE PAYLOAD AT COMPLEX 39
4.2 PERFORM ORBITER/PL INTEGRATION
4.3 ESTABLISH LAUNCH CONFIDENCE
4.4 PERFORM LAUNCH COUNTDOWN
5.0 (REF) PERFORM OTV MISSION
6.0 PERFORM POST LANDING OPERATIONS
GO TO 2.2

Figure 3-4. Cargo Bay OTV Functional Flow: IPF, Contd

OTV	SHUTTLE/CENTAUR TASK NUMBER	TASK DESCRIPTION	PROCEDURES	PERSONNEL REQUIRED ENG	MECH	TECH	INSP	PWR	LOCATION IPF	VAB	39A	TEAM	TASK TIME (HRS)	MANHOURS (HRS)	MANHOUR OPTIONAL TASKS
2.2		XPORT OTV TO IPF		2	4		2		SKID STRIP			STR	2	16	
2.2		XPORT OTV TO IPF		1		1	1		SKID STRIP			ELEC	2	6	
2.3(REF)	1.2(REF)	RCV & INSP ASE							X					0	
2.3.1	1.2.8	ASE MECH RCV & INSP	MECH-9001				3		X			STR	24	72	
2.3.2	1.2.9	ASE ELEC RCV & INSP	NET-9001				3		X			ELEC	24	72	
2.3.3	1.2.10	ASE INSTRU RCV & INSP	TLM-9003	1		1	1		X			INSTR	24	72	
2.3.4	1.2.13	ASE PNEU SYS RCVG PREPS	PNEU-9019	1	2		1		X			PNEU	16	64	
2.5(REF)	1.4(REF)	OTV RCV & INSP							X				-	0	
2.5.1	1.4.2	OTV MECH RCV & INSP	MECH-9000				3		X			STR	24	72	
2.5.2	1.4.4	OTV PROP/HYD RCVG PREPS	PROP-9001	2	4		2		X			PROP	16	128	
2.5.3	1.4.7	OTV PNEU SYS RCVG PREPS	PNEU-9019	2	4		2		X			PNEU	16	128	
2.5.4	1.4.8	OTV PROP TK PRG & SMPLG	PNEU-9002	1	2		1		X			PNEU	16	64	
2.5.5	1.4.11	OTV RCV & INSP ELEC	NET-9002				[illegible]		[illegible]			ELEC	24	72	
2.5.6	2.4.25	RCV/INSP INSTRU & RF EQUIP	TLM-9002	1								INSTR	8	24	
2.6		ASSEM OTV & INST AEROBRAKE		[illegible]								STR	16	160	
2.6		ASSEM OTV & INST AEROBRAKE										ELEC	8	48	
3.0(REF)		OTV PROCESSING											-	0	
3.1	2.1	MATE ASE TO FACILITY	[illegible]						X			STR	4	48	
3.2(REF)		ASE SUBSYSTEM CHECKOUT											-	0	
3.2.1	1.2.1	ASE PREPOWER I/F TEST	NE			1	1		X			ELEC	12	36	
3.2.2	1.2.2	ASE STD TURN-ON PROFILE	NET	1		1	1					ELEC	2	6	
3.2.2	1.2.2	ASE STD TURN-ON PROFILE	NET-	1								AV	2	2	
3.2.2	1.2.2	ASE STD TURN-ON PROFILE	NET-9007	2								INSTR	2	4	
3.2.2	1.2.2	ASE STD TURN-ON PROFILE	NET-9007					5				PWR	2	10	
3.2.3	1.2.3	ASE AV SUBSYS FCTN CO	NET-9000	1		1	1		X			ELEC	14	42	
3.2.3	1.2.3	ASE AV SUBSYS FCTN CO	NET-9000	1					X			AV	14	14	
3.2.3	1.2.3	ASE AV SUBSYS FCTN CO	NET-9000					5	X			PWR	14	70	
• 3.2.4	1.2.6	ASE PAVCS FCTN CO	PNEU-9006	1	2		1		X			PNEU	16		64
• 3.2.4	1.2.6	ASE PAVCS FCTN CO	PNEU-9006					5	X			PWR	16		80
3.2.5	2.2.10	INSTL ASE/FAC FL LINE I/F	PNEU-9003	2	4		2		X			PROP	8	64	
3.2.5	2.2.10	INSTL ASE/FAC FL LINE I/F	PNEU-9003	2	4		1		X			PNEU	8	56	
3.2.5	2.2.10	INSTL ASE/FAC FL LINE I/F	PNEU-9003	2	4		1		X			FLUID	8	56	

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SAMPLE

Table 3-2. GBOTV Aftcargo Carrier Ground Turnaround Processing for IPF: Fully Automated

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A comparison of manhour requirements taken from the worksheets is presented in Table 3-3 to show differences between options for each task. It has been summarized to Level 2 and gives the manhour requirements for the two extreme options for both initial and turnaround processing. The total manhours at the bottom of the table shows a distinct reduction in manhours for the IPF with full automation for both initial and turnaround operations. This data will be used in the trade study.

A turnaround timeline for the IPF with full automation is shown in Figure 3-5. The turnaround processing takes 10 weeks to accomplish for a single-shift operation assuming a 5-day mission. Eight Level 2 timelines were produced for the cargo bay reusable GBOTV configuration including both initial and turnaround operations.

The results of going to a double-shift operation are shown in the bottom row of Table 3-4. The table is a manpower summary for the options, including initial and turnaround processing manhours, average and peak crew requirements per shift, the number of shifts required, and the elapsed time for a double-shift, 5-day workweek. The turnaround manhours are broken down to three values: minimum, maximum, and nominal. The minimum value does not include any of the optional turnaround tasks. It is assumed that the vehicle returns from a mission without faults and does not need preventive maintenance or reconfiguration. The maximum manhours include all of the optional tasks. The maximum assumes total testing is required as in the initial processing operations, the same amount as initial processing. This means that all subsystems are fully checked and that a full-up terminal countdown with cryogenic propellant loading is required. The nominal figure is derived from the reliability estimate which establishes the amount of maintenance required and reconfiguration estimates as a result of mission model assessments. The nominal manhours are estimated to be about 10% of the optional task manhours added to the minimum manhours.

The peak crew requirements shown all personnel needed to support intense parallel operations such as launch countdown. The average crew required may be supplemented by factory people during these parallel operations.

3.1.5 TRADE STUDY. The ground processing data provided inputs to the cargo bay reusable GBOTV trade study along with the ground rules and assumptions listed below:

a. Nominal mission model used to calculate operations cost.

b. Baseline life-cycle cost (LCC) of $37B used for GBOTV.

c. Forty-mission life per vehicle.

d. One vehicle per mission.

e. GSE has been included for a single production site and a single operational site.

f. Test and checkout equipment is assumed to account for 70% of the GSE costs. Processing equipment accounts for half of test and checkout equipment.

g. Automated scenarios were assumed to require more complex GSE than non-automated scenarios.

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS			
		INITIAL PROCESSING		TURNAROUND	
		S/C FACILITY S/C AUTOMATION	INTEGRATED FAC. FULLY AUTOMATED	S/C FACILITY S/C AUTOMATION	INTEGRATED FAC. FULLY AUTOMATED
2.1	UNLOAD OTV FROM AIRCRAFT	72	72	–	–
2.2	TRANSPORT OTV TO HANGAR J/IPF	22	22	22	22
2.3	RECEIVE AND INSPECT ASE	280	280	280	280
2.4	TRANSPORT ASE TO OTVPF	44	–	44	–
2.5	OTV RECEIVE AND INSPECT	488	488	488	488
2.6	ASSEMBLE OTV AND INSTALL BALLUTE	208	208	208	208
2.7	TRANSPORT OTV TO OTVPF	108	–	108	–
3.1	MATE ASE TO FACILITY	48	48	48	48
3.2	PERFORM ASE SUBSYSTEM CHECKOUT	2265	788	1225	456
3.3	MATE OTV TO ASE	1312	1040	1032	840
3.4	PERFORM SUBSYSTEM CHECKOUT	4238	1764	2930	1376
3.5	VERIFY SUBSYSTEM READINESS	3496	1772	920	720
3.6	TRANSPORT OTV TO VPF	52	–	52	–
3.7	RECEIVE OTV AT VPF	304	–	304	–

Table 3-3. Cargo Bay OTV Manhour Requirements

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS			
		INITIAL PROCESSING		TURNAROUND	
		S/C FACILITY S/C AUTO-MATION	INTEGRATED FAC. FULLY AUTOMATED	S/C FACILITY S/C AUTO-MATION	INTEGRATED FAC. FULLY AUTOMATED
3.8	PREPARE OTV FOR SPACECRAFT MATING	264	80	104	
3.9	MATE OTV AND SPACECRAFT	184	104	184	104
3.10	PERFORM OTV AND SPACECRAFT CHECKOUT	342	154	342	154
3.11	VERIFY ORBITER INTERFACE	136	96	136	96
3.12	TRANSPORT PAYLOAD TO CX39	418	418	418	418
4.1	RECEIVE PAYLOAD AT CX39	216	176	216	176
4.2	PERFORM ORBITER/PAYLOAD INTEGRATION	828	708	828	708
4.3	ESTABLISH LAUNCH CONFIDENCE	768	624	768	624
4.4	PERFORM LAUNCH COUNTDOWN	648	360	648	360
5.0	PERFORM OTV MISSION	–	–	–	–
6.0	PERFORM POST MISSION OPS	–	–	384	384
7.0	PERFORM MAINTENANCE & SERVICING	–	–	(40)	(40)
8.0	RECONFIGURE OTV FOR MISSION	–	–	(80)	(80)
	TOTAL MANHOURS	16741	9202	11689	7462

( ) OPTIONAL TASKS NOT INCLUDED IN TOTAL

2-2 (7/15)A

Table 3-3. Cargo Bay OTV Manhour Requirements, Contd

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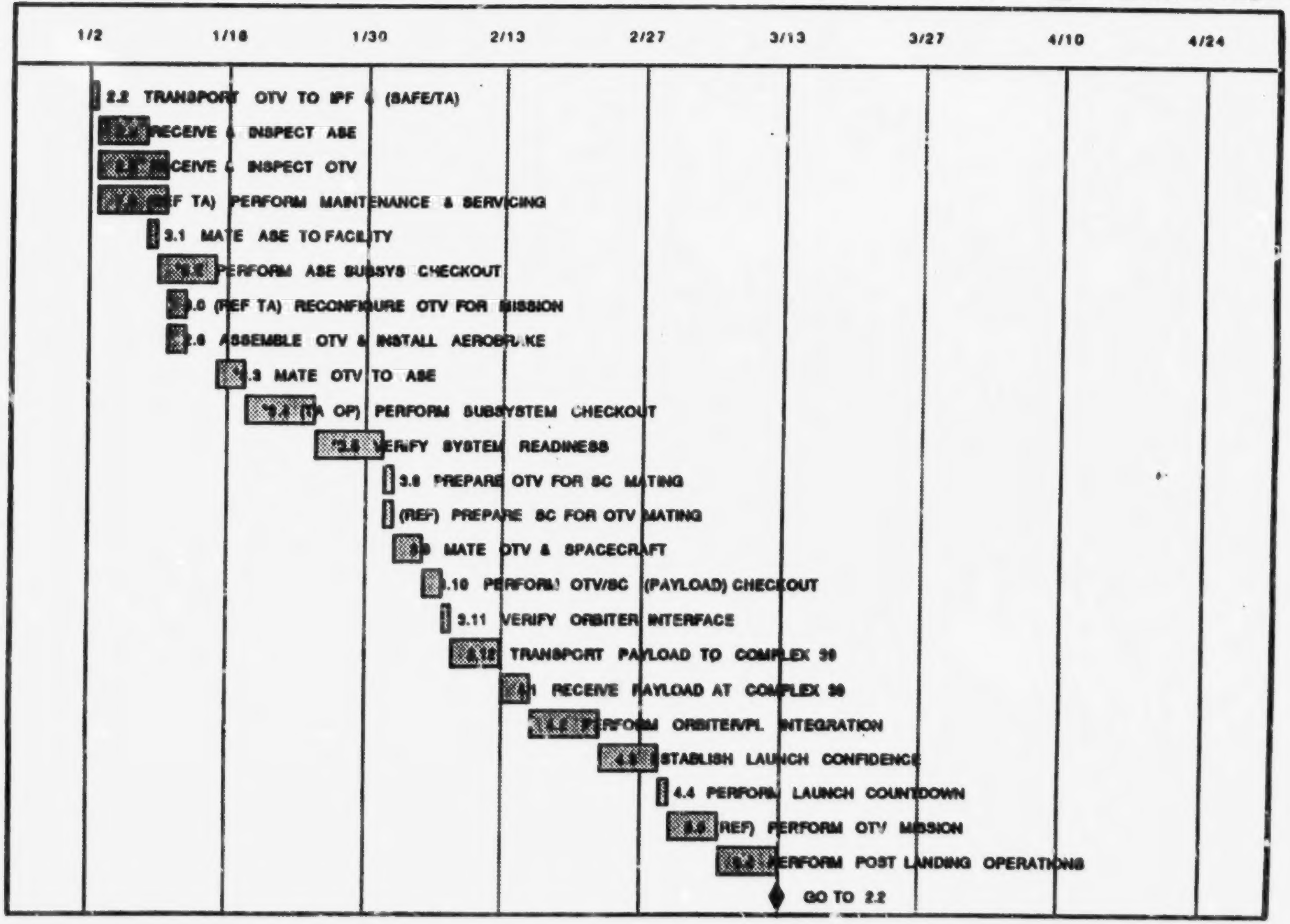

omation,

RESOURCE COMMITTMENT / OPTION	S/C FACILITY WITH S/C AUTOMATION	S/C FACILITY FULLY AUTOMATED	INTEGRATED FACILITY WITH S/C AUTOMATION	INTEGRATED FULLY AUTOMATED
INITIAL PROCESSING (MANHOURS)	16741	14186	11867	9202
TURNAROUND (MANHOURS)				
MIN	11689	10462	8647	7462
MAX	17413	14734	12667	9962
NOMINAL	12369	10997	9157	7820
AVERAGE CREW REQ/SHIFT	25	22	21	20
PEAK CREW REQ BY DISCIPLINE PER SHIFT	95	95	85	85
ELAPSED TIME (SHIFTS)	63	63	55	50
5-DAY WORK WEEK DOUBLE SHIFTS (WEEKS)	6.3	6.3	5.5	5

EXTRAPOLATING FROM A DATA BASE FOR PROCESSING A CRYOGENIC STAGE IN ORBITER.

272.353-23

Table 3-4. Cargo Bay OTV Manpower Summary

h. Pad substructure and umbilical towers assumed available for the Shuttle/Centaur-Type (Pad 36A) facility options.

i. All costs reported in CY 1986 dollars.

j. Composite rate of $43/hour used for cost recurring operations.

k. No fee is included.

The trade study results are presented in the trade comparison Table 3-5. The table lists the facility and automation options horizontally and the evaluation criteria vertically. The criteria consist of processing manhours for each operation including initial and turnaround operations, total manhours for 257 missions, manhour cost, number of vehicles and processing bays required to meet the Revision 8 nominal mission model launch schedule, facility and support equipment cost, and total vehicle ground processing costs as the bottom line. The actual number of vehicles required to satisfy the mission model is seven; however, a spare vehicle is included in the estimate. The analysis also did not account for multiple vehicle missions; only one vehicle per mission is an analysis ground rule. The bottom-line results favor the IPF with a full level of automation. Although only a slim margin exists between Shuttle/Centaur level of automation and full automation, there are other factors to support full automation. These include increased safety in hazardous tasks and increased efficiency and reliability because of reduced personnel errors and reduced interaction with the equipment.

3.1.6 RECOMMENDATIONS - CARGO BAY PROCESSING. An IPF, fully automated vehicle, and a double-shift operation are recommended for ground processing a cargo bay GBOTV for the following reasons:

a. IPF
    1. Reduces transportation and retesting.
    2. Accommodates vehicle more efficiently.
    3. Reduces manhours.

b. Automated checkout
    1. Reduces manhours.
    2. Reduces potential for manual errors.
    3. Increases safety.

c. Double-shift operation
    1. Reduced number of vehicles in process.
    2. Reduced number of processing bays.

3.1.7 RECOMMENDED TASK DEFINITIONS. The task description sheets (see Table 3-6 as an example) contain data peculiar to each Level 2 task of the OTV turnaround. The task identification code and descriptor are the same as those used throughout the study. The purpose and a narrative description of the task are presented along with the resource requirements, task duration and frequency. The resource requirements include the crew size and manhour requirements for the tasks in addition to the accommodations required to perform the tasks.

CRITERIA / OPTION		S/C FACILITY WITH S/C AUTOMATION	INTEGRATED FACILITY WITH S/C AUTOMATION	S/C FACILITY FULLY AUTOMATED	INTEGRATED FULLY AUTOMATED
PROCESSING MANHOURS	INITIAL	16,741	11,867	14,186	9,202
	TURNAROUND (NORMAL) (NOMINAL)(3)	11.689 12,369	8,647 9,157	10,462 10,997	7,462 7,820
VEHICLES/BAYS TO MEET MISSION LAUNCH SCHEDULE(1)		1994 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES	1994 - 1 BAY 1996 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES	1994 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES	1994 - 1 BAY 1996 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES
TOTAL MANHOURS(5) $\times 10^3$		3,209	2,372	2,849	2,026
MANHOUR COST ($M)		138	102	123	87
FACILITY COST ($M)		27	28	27	28
SUPPORT EQUIPMENT COST ($M)		27	27	37	37
COST ($M)(2)		192	157	187(4)	152(4)
					SELECTED ✓

(1) DOES NOT CONSIDER MULTIPLE STAGES
(2) DIRECT VEHICLE OPERATIONS COSTS
(3) NOMINAL = NORMAL & MAINTENANCE & SERVICING PER MISSION AVERAGE & OTV RECONFIGURE COVERAGE & 10% OPTIONAL TASKS
(4) DOESN'T INCLUDE COSTS FOR ADDITIONAL OTV WEIGHT FOR AUTOMATED CHECKOUT.
(5) 257 MISSIONS/8 INITIAL PROCESSING

272.353-24

Table 3-5. Cargo Bay GBOTV Operations Trade Study

TASK-IDENT **DESCRIPTOR**
3.3 MATE OTV TO ASE

PURPOSE
MATE OTV TO ASE TO ALLOW CHECKOUT OF THE INTEGRATED OTV/ASE

TASK DESCRIPTION
ASE FINAL PREPARATIONS FOR MATE. MATE OTV TO ASE AND CONNECT MECHANICAL, ELECTRICAL AND FLUID INTERFACES AND PREPARE FOR SUBSYSTEM CHECKOUT.

TASK DURATION
56 HOURS (7 DAYS)

TASK FREQUENCY
INITIAL DELIVERY TO LAUNCH SITE
ONCE EVERY FORTY MISSIONS

RESOURCE REQUIREMENTS

CREW

	CREW SIZE	**MANHOURS**
ENGINEERS	10	320
MECHANICS	13	352
TECHNICIANS	3	104
INSPECTORS	7	224
POWER CREW	5	40
TOTAL	38	1040

ACCOMMODATIONS
IPF
HANDLING/LIFTING EQUIPMENT

SPARES

OTHER VEHICLE SYSTEMS AFFECTED

272.363-28

Table 3-6. Task Description Sheet: Initial Ground Processing - Cargo Bay - IPF

3.2 GROUND-BASED/EXPENDABLE OTV SHUTTLE/CENTAUR DERIVATIVE

3.2.1 **EXPENDABLE GBOTV DEFINITION**. Figure 3-6 shows an example of an expendable OTV. The stage is a derivative of the Shuttle/Centaur with separated structurally stabilized tanks.

3.2.2 **GBOTV - EXPENDABLE PROCESSING REQUIREMENTS**. The GBOTV - expendable processing requirements were obtained in the same manner as the cargo bay GBOTV requirements. In fact, the requirements for the launch phase are the same as for the cargo bay launch phase (see Section 3.1.2) except for a few minor requirements that deal with a reusable stage (such as an aerobrake) that are not needed.

3.2.3 **FUNCTIONAL FLOWS**. The expendable GBOTV functional flows for the different facilities were generated in the same manner as the GBOTV. Again, the launch phase is the same as the cargo bay GBOTV launch phase (see Section 3.1.3), except for a few minor differences that deal with a reusable stage (such as an aerobrake) that are not needed.

3.2.4 **MANPOWER/TIMELINES**. As stated in the previous two sections, processing the expendable GBOTV is practically identical to the launch phase of the cargo bay GBOTV. The manpower and timelines are essentially the same (see Section 3.1.4).

3.2.5 **TRADE STUDY**. As stated previously, for the expendable OTV we only generated trade study data for two of the facility/processing combinations. Table 3-7 compares the facility and vehicle options for processing the expendable GBOTV. The options are evaluated with the criteria listed in the left vertical column. The comparison resulted in a lower operations cost for an IPF, combined with a fully automated vehicle, which is the recommended option.

3.2.6 **RECOMMENDATIONS**. An IPF, a fully automated vehicle, and a double-shift operation are recommended for ground processing an expendable OTV for the following reasons:

a. IPF

    1. Reduces transportation and retesting.

    2. Accommodates vehicle more efficiently.

    3. Reduces manhours.

b. Automated checkout

    1. Reduces manhours.

    2. Reduces potential for manual errors.

    3. Increases safety.

c. Double-shift operation

    1. Reduced number of vehicles in process.

    2. Reduced number of processing bays.

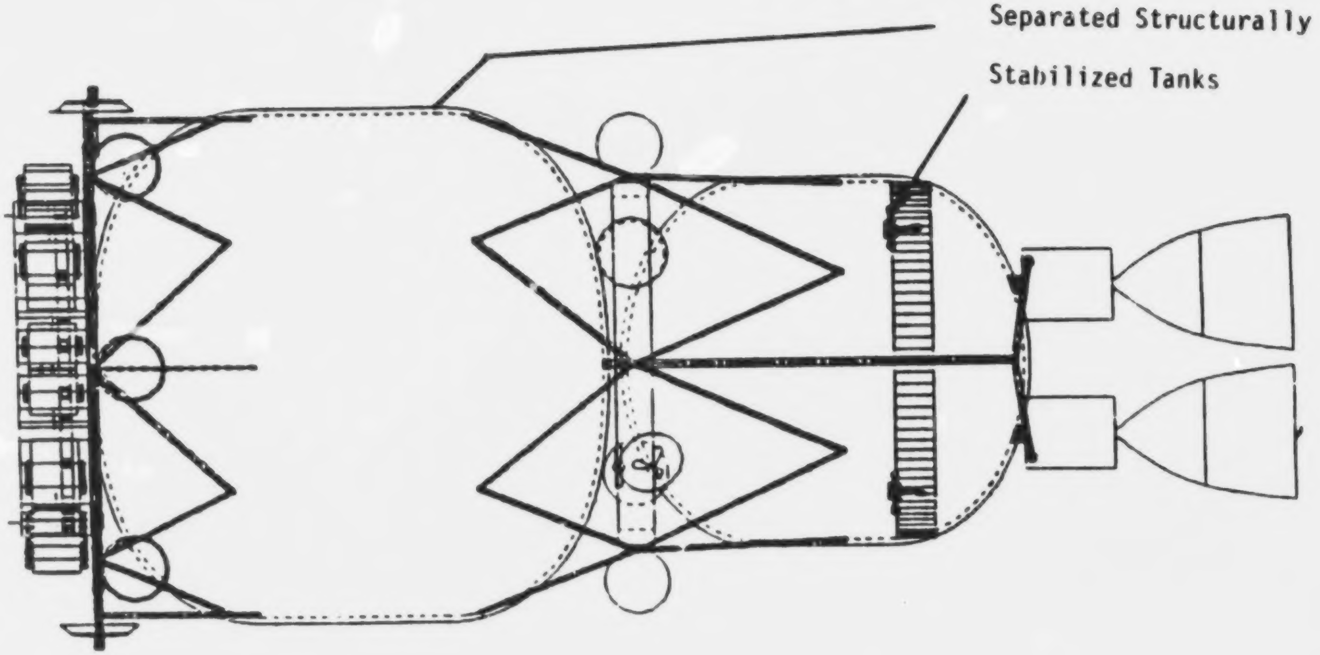

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Figure 3-6. Expendable GBOTV: Shuttle Centaur Derivative

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CRITERIA / OPTION		S/C FACILITY WITH S/C AUTOMATION	INTEGRATED FACILITY WITH S/C AUTOMATION	S/C FACILITY FULLY AUTOMATED	INTEGRATED FULLY AUTOMATED
PROCESSING MANHOURS	INITIAL	16,681			9,138
	TURNAROUND				
VEHICLES/BAYS TO MEET MISSION LAUNCH SCHEDULE*		1994 - 2 BAYS 1998 - 3 BAYS 257 VEHICLES			1994 - 2 BAYS 2006 - 3 BAYS 257 VEHICLES
TOTAL MANHOURS x 10^3		42,870			2,348
MANHOUR COST ($M) $43/Hr		184			101
FACILITY COST ($M)		27			28
SUPPORT EQUIPMENT COST ($M)		27			37
COST ($M)**		238			166

* DOES NOT CONSIDER MULTIPLE STAGES
** DIRECT VEHICLE OPERATIONS COSTS

272.353-27

Table 3-7. Expendable GBOTV Operations Trade Study

3.3 GROUND-BASED ACC OTV

3.3.1 ACC GBOTV DEFINITION. The ACC-launched OTV is shown in Figure 3-7. This concept was developed by Martin Marietta during the Phase A definition studies. The OTV is attached to the aft end of the external tank. A deployable aerobrake is used for an aero-assist device.

3.3.2 ACC GBOTV PROCESSING REQUIREMENTS. The processing requirements were obtained in the same manner as the cargo bay GBOTV (see Section 3.1.2). The fact that the OTV attaches to the aft end of the external tank instead of being placed in the cargo bay was included in the requirements.

3.3.3 FUNCTIONAL FLOWS. Figure 3-8 is a Level 2 functional flow diagram of the ACC reusable GBOTV, which is processed using Shuttle/Centaur-type facilities. The flow included factory processing, initial processing, and turnaround operations. Factory processing is shown here, because the baseline Shuttle/Centaur data included some of these functions. The factory processing functions have been identified and are deleted from the operations analysis.

The initial processing of the vehicle begins by unloading the OTV from the delivery aircraft (2.1) and ends when the vehicle is launched (4.4).

Turnaround operations include all of the initial processing functions except 2.1 and add functions 5.0 through 8.0 to the flow. During turnaround operations, the ASE and vehicle will be checked out only to the extent necessary. The amount of checkout required will be determined by flight data analysis, and maintenance/reconfiguration performed. An asterisk in front of the functional number denotes those functions that would be affected by checkout requirements. Similar flows were generated for the integrated facility.

3.3.4 MANPOWER ASSESSMENT/TIMELINE. Timelines and manpower requirements were generated for the ACC OTV processing in a similar manner as the ones for the cargo bay OTV (see Section 3.1.4). Table 3-8 is a summary of the manpower requirements at the two indicated facilities for initial processing and turnaround. As can be seen, there is a considerable difference in manpower for the different approaches.

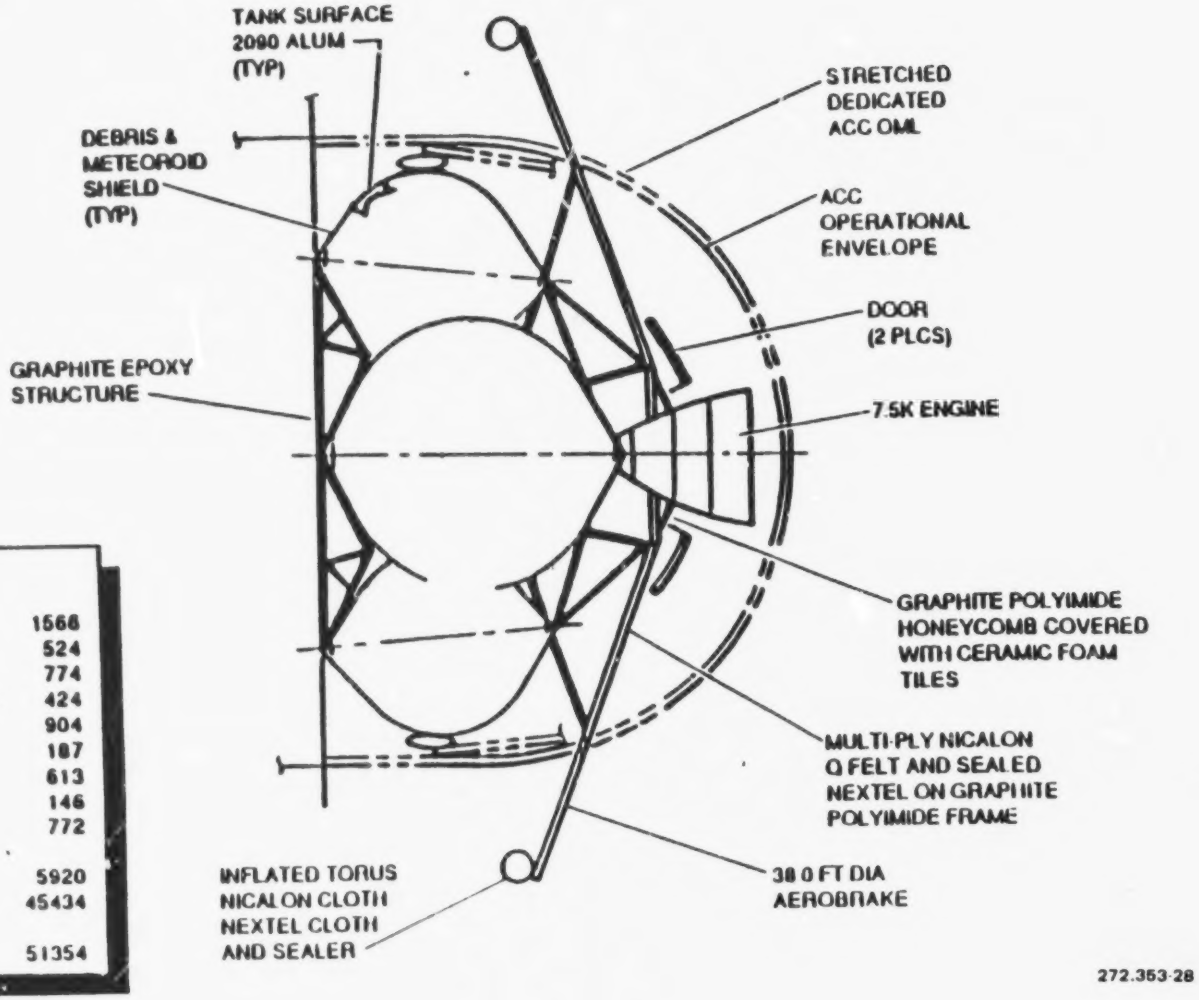
3.3.5 TRADES. Table 3-9 compares the facility and vehicle options for processing the ACC reusable GBOTV. The options are evaluated with the criteria listed in the left vertical column. The comparison resulted in a lower operations cost for an IPF, combined with a fully automated vehicle, which is the recommended option.

Table 3-10 shows the comparison of the manpower requirements to process a cargo bay OTV and an ACC OTV.

3.3.6 RECOMMENDATIONS. An IPF, a fully automated vehicle, and a double-shift operation are recommended for processing an ACC OTV for the following reasons:

a. IPF

   1. Reduces transportation and retesting.
   2. Accommodates vehicle more efficiently.
   3. Reduces manhours.



WEIGHT	
AEROBRAKE	1566
TANKS	524
STRUCTURE	774
ENVIRONMENTAL CONTROL	424
MAIN PROPULSION	904
ORIENTATION CONTROL	187
ELECTRIC SYSTEMS	613
G.N & C	146
CONTINGENCY 15%	772
DRY WEIGHT	5920
PROPELLANTS, ETC.	45434
LOADED WEIGHT	51354

Figure 3-7. ACC GBOTV

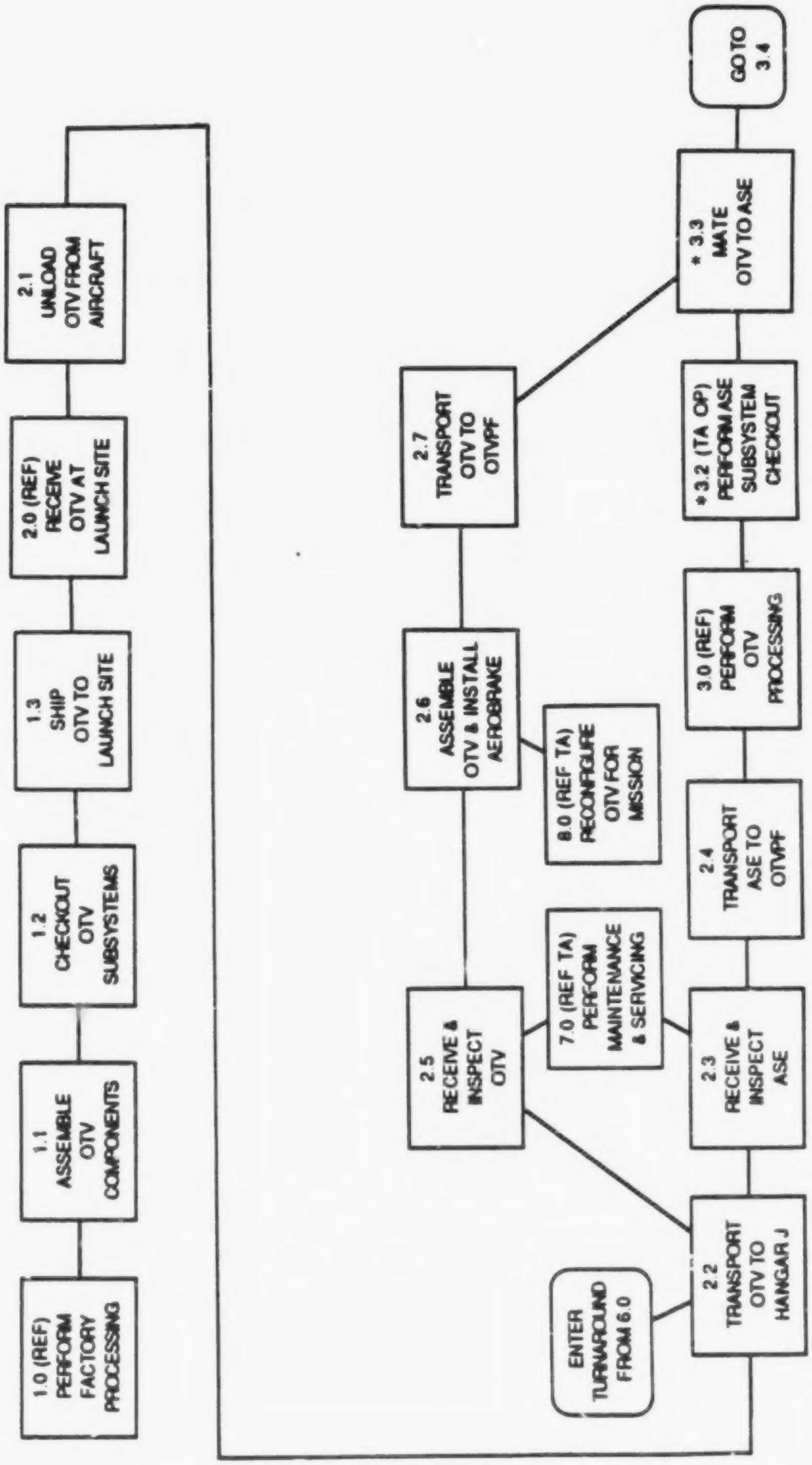

1.0 (REF) PERFORM FACTORY PROCESSING
1.1 ASSEMBLE OTV COMPONENTS
1.2 CHECKOUT OTV SUBSYSTEMS
1.3 SHIP OTV TO LAUNCH SITE
2.0 (REF) RECEIVE OTV AT LAUNCH SITE
2.1 UNLOAD OTV FROM AIRCRAFT
ENTER TURNAROUND FROM 6.0
2.2 TRANSPORT OTV TO HANGAR J
2.5 RECEIVE & INSPECT OTV
7.0 (REF TA) PERFORM MAINTENANCE & SERVICING
2.3 RECEIVE & INSPECT ASE
2.4 TRANSPORT ASE TO OTVPF
2.6 ASSEMBLE OTV & INSTALL AEROBRAKE
8.0 (REF TA) RECONFIGURE OTV FOR MISSION
3.0 (REF) PERFORM OTV PROCESSING
2.7 TRANSPORT OTV TO OTVPF
* 3.2 (TA OP) PERFORM ASE SUBSYSTEM CHECKOUT
* 3.3 MATE OTV TO ASE
GO TO 3.4

Figure 3-8. ACC OTV Functional Flow: Shuttle/Centaur Type Facility

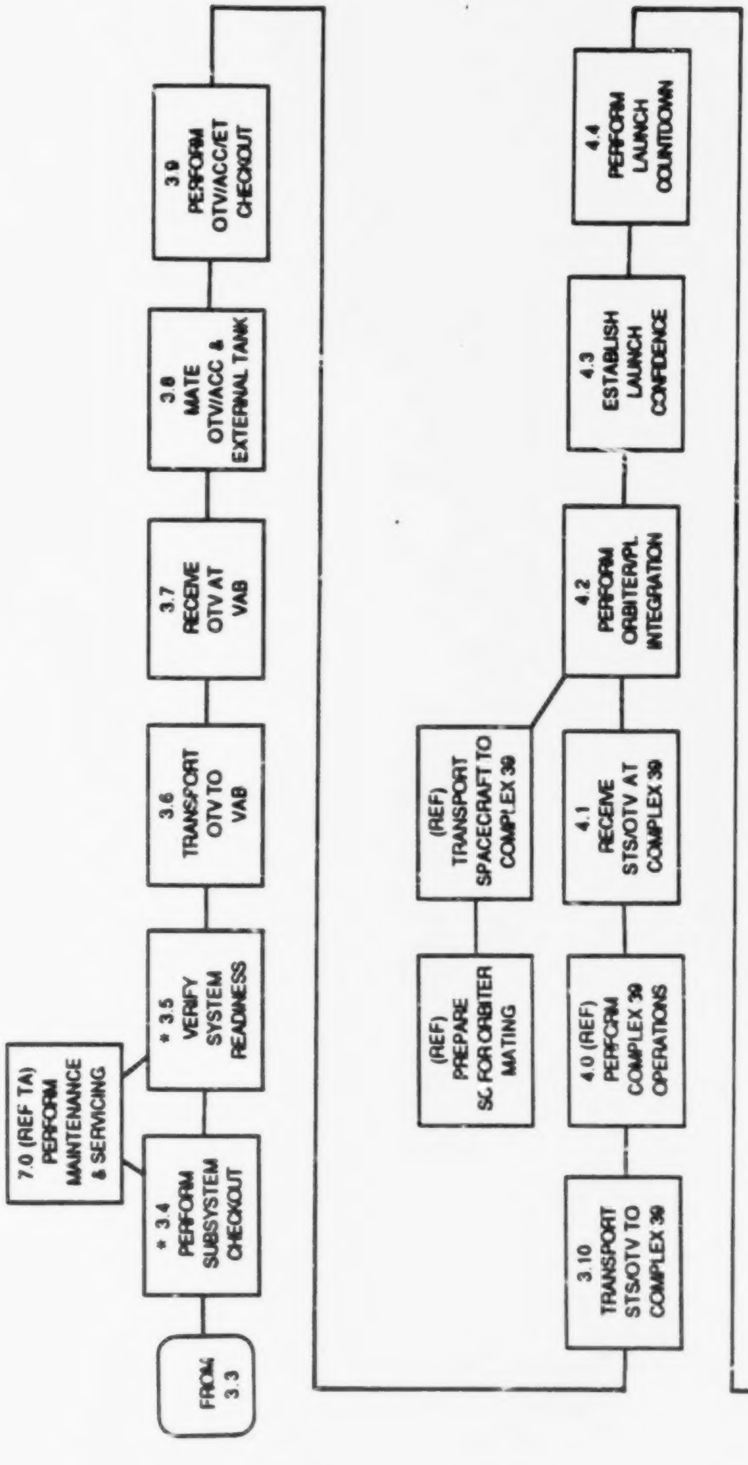

FROM 3.3
* 3.4 PERFORM SUBSYSTEM CHECKOUT
7.0 (REF TA) PERFORM MAINTENANCE & SERVICING
* 3.5 VERIFY SYSTEM READINESS
3.6 TRANSPORT OTV TO VAB
3.7 RECEIVE OTV AT VAB
3.8 MATE OTV/ACC & EXTERNAL TANK
3.9 PERFORM OTV/ACC/ET CHECKOUT
3.10 TRANSPORT STS/OTV TO COMPLEX 39
4.0 (REF) PERFORM COMPLEX 39 OPERATIONS
(REF) PREPARE SC FOR ORBITER MATING
(REF) TRANSPORT SPACECRAFT TO COMPLEX 39
4.1 RECEIVE STS/OTV AT COMPLEX 39
4.2 PERFORM ORBITER/PL INTEGRATION
4.3 ESTABLISH LAUNCH CONFIDENCE
4.4 PERFORM LAUNCH COUNTDOWN
5.0 (REF) PERFORM OTV MISSION
6.0 PERFORM POST LANDING OPERATIONS
GO TO 2.2

Figure 3-8. ACC OTV Functional Flow: Shuttle/Centaur Type Facility, Contd

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS			
		INITIAL PROCESSING		TURNAROUND	
		S/C FACILITY S/C AUTOMATION	INTEGRATED FAC. FULLY AUTOMATED	S/C FACILITY S/C AUTOMATION	INTEGRATED FAC. FULLY AUTOMATED
2.1	UNLOAD OTV FROM AIRCRAFT	72	72	--	--
2.2	TRANSPORT OTV TO HANGAR J/IPF	22	22	22	22
2.3	RECEIVE AND INSPECT ASE	280	280	280	280
2.4	TRANSPORT ASE TO OTVPF	44	--	44	--
2.5	OTV RECEIVE AND INSPECT	488	488	488	488
2.6	ASSEMBLE OTV AND INSTALL BALLUTE	208	208	208	208
2.7	TRANSPORT OTV TO OTVPF	108	--	108	--
3.1	MATE ASE TO FACILITY	48	48	48	48
3.2	PERFORM ASE SUBSYSTEM CHECKOUT	2265	788	1225	456
3.3	MATE OTV TO ASE	1032	840	1032	840
3.4	PERFORM SUBSYSTEM CHECKOUT	4182	1748	2890	1312
3.5	VERIFY SUBSYSTEM READINESS	3472	1756	552	408
3.6	TRANSPORT OTV TO VAB	52	52	52	52
3.7	RECEIVE OTV AT VAB	424	304	264	224

Table 3-8. ACC OTV Manhour Requirements

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS			
		INITIAL PROCESSING		TURNAROUND	
		S/C FACILITY S/C AUTOMATION	INTEGRATED FAC. FULLY AUTOMATED	S/C FACILITY S/C AUTOMATION	INTEGRATED FAC. FULLY AUTOMATED
3.8	MATE OTV/ACC & ET	884	684	884	684
3.9	PERFORM OTV/ET CHECKOUT	288	288	288	288
3.10	TRANSPORT STS/OTV TO CX39	80	80	80	80
4.1	RECEIVE STS/OTV AT CX39	128	88	128	88
4.2	PERFORM ORBITER/PAYLOAD INTEGRATION	620	500	620	500
4.3	ESTABLISH LAUNCH CONFIDENCE	768	624	768	624
4.4	PERFORM LAUNCH COUNTDOWN	648	408	648	408
5.0	PERFORM OTV MISSION	--	--	--	--
6.0	PERFORM POST MISSION OPS	--	--	384	384
7.0	PERFORM MAINTENANCE & SERVICING	--	--	40	40
8.0	RECONFIGURE OTV FOR MISSION	--	--	80	80
	TOTAL MANHOURS	16113	9278	11133	7514

Table 3-8. ACC OTV Manhour Requirements, Contd

CRITERIA / OPTION		S/C FACILITY WITH S/C AUTOMATION	INTEGRATED FACILITY WITH S/C AUTOMATION	S/C FACILITY FULLY AUTOMATED	INTEGRATED FULLY AUTOMATED
PROCESSING MANHOURS	INITIAL	16,113			9,278
	TURNAROUND	11,709			7,763
VEHICLES/BAYS TO MEET MISSION LAUNCH SCHEDULE*		1994 - 2 BAYS 1998 - 3 BAYS 8 VEHICLES			1994 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES
TOTAL MANHOURS $\times 10^3$		3,040			2,006
MANHOUR COST ($M) $43/Hr		131			86
FACILITY COST ($M)		27			28
SUPPORT EQUIPMENT COST ($M)		27			37
COST ($M)** Δ		185			151

* DOES NOT CONSIDER MULTIPLE STAGES

** DIRECT VEHICLE OPERATIONS COSTS

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Table 3-9. ACC GBOTV Operations Trade Study

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS			
		INITIAL PROCESSING		TURNAROUND	
		RECOMMEND ACC	RECOMMEND CARGO BAY	RECOMMEND ACC	RECOMMEND CARGO BAY
2.1	UNLOAD OTV FROM AIRCRAFT	72	72	--	--
2.2	TRANSPORT OTV TO HANGAR J/IPF	22	22	22	22
2.3	RECEIVE AND INSPECT ASE	280	280	280	280
2.4	TRANSPORT ASE TO OTVPF	--	--	--	--
2.5	OTV RECEIVE AND INSPECT	488	488	488	488
2.6	ASSEMBLE OTV AND INSTALL BALLUTE	208	208	208	208
2.7	TRANSPORT OTV TO OTVPF	--	--	--	--
3.1	MATE ASE TO FACILITY	48	48	48	48
3.2	PERFORM ASE SUBSYSTEM CHECKOUT	788	788	456	456
3.3	MATE OTV TO ASE	840	1040	840	840
3.4	PERFORM SUBSYSTEM CHECKOUT	1748	1764	1312	1376
3.5	VERIFY SUBSYSTEM READINESS	1756	1772	408	720
3.6	TRANSPORT OTV TO VPF/VAB	52	--	52	--
3.7	RECEIVE OTV AT VPF/VAB	304	--	224	--

Table 3-10. ACC/Cargo Bay Processing Manpower Comparison

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS			
		INITIAL PROCESSING		TURNAROUND	
		RECOMMEND ACC	RECOMMEND CARGO BAY	RECOMMEND ACC	RECOMMEND CARGO BAY
3.8	PREPARE OTV FOR SPACECRAFT MATING	--	80	--	--
3.9	MATE OTV AND SPACECRAFT	684	102	684	104
3.10	PERFORM OTV AND SPACECRAFT CHECKOUT	280	154	288	182
3.11	VERIFY ORBITER INTERFACE	--	96	--	96
3.12	TRANSPORT PAYLOAD TO CX39	80	418	80	418
4.1	RECEIVE PAYLOAD AT CX39	88	176	88	176
4.2	PERFORM ORBITER/PAYLOAD INTEGRATION	500	709	500	708
4.3	ESTABLISH LAUNCH CONFIDENCE	624	624	624	624
4.4	PERFORM LAUNCH COUNTDOWN	408	360	408	360
5.0	PERFORM OTV MISSION	--	--	--	--
6.0	PERFORM POST MISSION OPS	--	--	384	384
7.0	PERFORM MAINTENANCE & SERVICING	--	--	40	40
8.0	RECONFIGURE OTV FOR MISSION	--	--	80	80
	TOTAL MANHOURS	9278	9202	11133	7610

Table 3-10. ACC/Cargo Bay Processing Manpower Comparison, Contd

b. Automated checkout
   1. Reduces manhours.
   2. Reduces potential for manual errors.
   3. Increases safety.

c. Double-shift operation
   1. Reduced number of vehicles in process.
   2. Reduced number of processing bays.

The integrated facility simplifies the operation with an improved facility and reduced number of transport tasks. The two-shift operation allows an acceptable number of vehicles (in process) and processing bays required to meet the Rev. 8 nominal mission model.

3.4 SBOTV

3.4.1 SBOTV REFERENCED CONFIGURATION (SYNTHESIZED VERSION). Figure 3-9 shows the SBOTV concept which is being used for this study. This is a synthesized version. It is launched dry in the cargo bay and assembled and operated in low earth orbit (LEO) at the Space Station.

3.4.2 SBOTV PROCESSING REQUIREMENTS. The processing requirements were obtained in the same manner as the cargo bay GBOTV (see Section 3.1.2). The fact that the SBOTV must be disassembled and launched in two Shuttle flights was taken into account.

3.4.3 FUNCTIONAL FLOWS. Figure 3-10 is a Level 2 functional flow diagram of the SBOTV, which is processed using Shuttle/Centaur-type facilities. The flow includes factory processing and initial processing. Factory processing is shown here, because the baseline Shuttle/Centaur data included some of these functions. The factory processing functions have been identified and are deleted from the operations analysis.

The initial processing of the vehicle begins by unloading when the vehicle is launched (2.1) and ends when the vehicle is launched (4.4).

This ground processing for a new complete vehicle is expected to occur about eight times between 1994 and 2010 according to the Revision 8 nominal mission model.

Figure 3-11 a Level 2 functional flow diagram of the SBOTV, which is processed using IPF. The flow includes factory processing and initial processing. Factory processing is shown here, because the baseline Shuttle/Centaur data included some of these functions. The factory processing functions have been identified and are deleted from the operations analysis.

The initial processing of the vehicle begins by unloading the OTV from the delivery aircraft (2.1) and ends when the vehicle is launched (4.4).

This ground processing for a new complete vehicle is expected to occur about eight times between 1994 and 2010 according to the Revision 8 nominal mission model.

MISSION CAPABILITY	
• GEO CIRCULAR	
EXPENDABLE	31,890 LB
REUSABLE	20,000 LB
• MAXIMUM DURATION	60 HRS
• GEO SERVICE STATION LOGISTICS	12,000 UP/4,000 DOWN
STAGE DESCRIPTION	
• DRY WEIGHT	9,070 LB
• BURNOUT WEIGHT	10,460 LB
• USABLE MAIN PROPELLANT	58,540 LB
• STAGE IGNITION WEIGHT	69,000 LB
• AIRBORNE SUPPORT EQUIPMENT	TBD
PROPULSION	
• PROPELLANT TYPE	O_2/H_2 (1 ATM)
• NO. MAIN ENGINE	2
• MIXTURE RATIO/ISP	6:1/485
• AVERAGE THRUST LEVEL	5,000 LB (PER ENG.)
• RCS PROPELLANT	N_2H_4
AVIONICS	
• TYPE	3 STRING
• POWER	FUEL CELL (PROPELLANT GRADE REACTANTS)

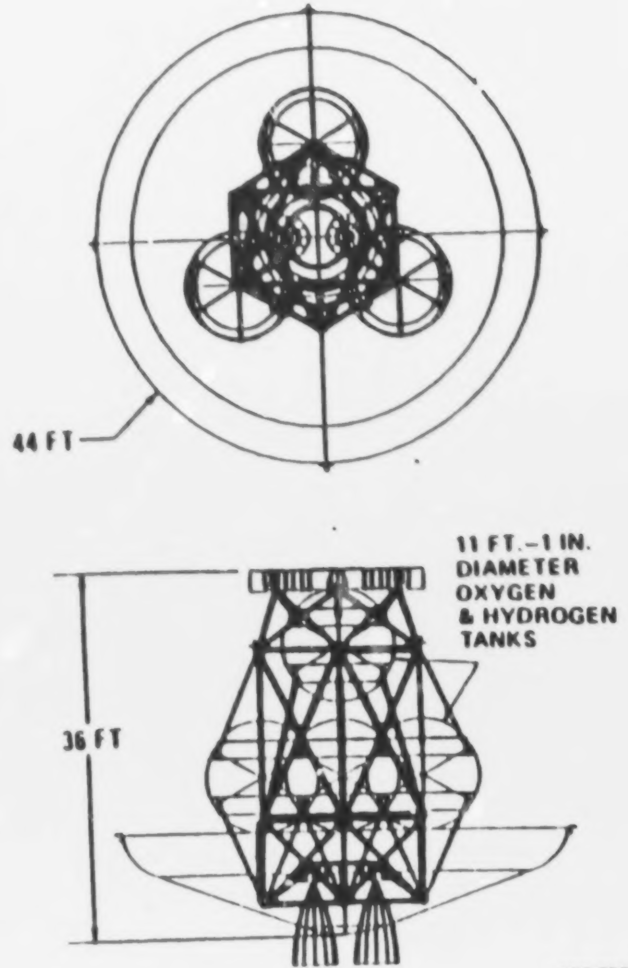

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Figure 3-9. S~~G~~BOTV Reference Configuration (Synthesized Version)

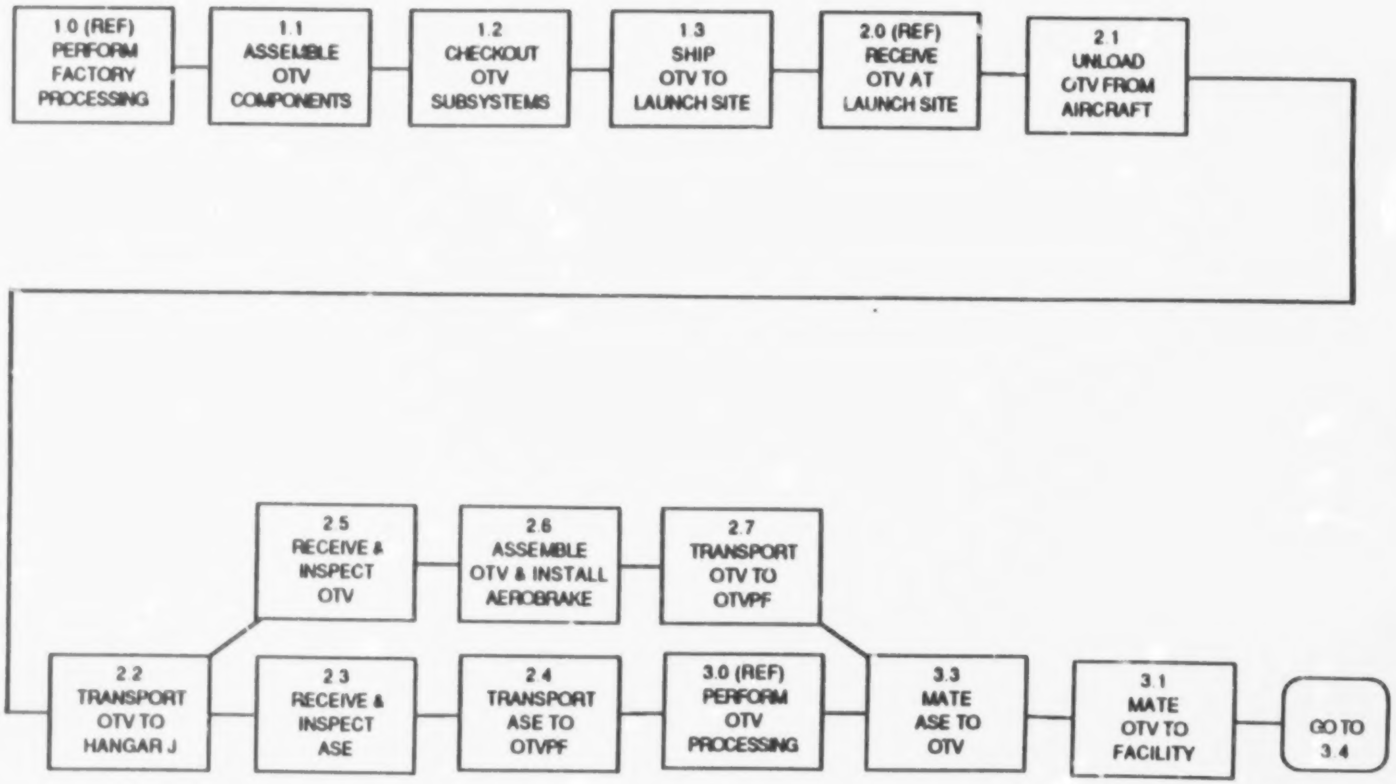
1.0 (REF) PERFORM FACTORY PROCESSING
1.1 ASSEMBLE OTV COMPONENTS
1.2 CHECKOUT OTV SUBSYSTEMS
1.3 SHIP OTV TO LAUNCH SITE
2.0 (REF) RECEIVE OTV AT LAUNCH SITE
2.1 UNLOAD OTV FROM AIRCRAFT
2.2 TRANSPORT OTV TO HANGAR J
2.5 RECEIVE & INSPECT OTV
2.6 ASSEMBLE OTV & INSTALL AEROBRAKE
2.7 TRANSPORT OTV TO OTVPF
2.3 RECEIVE & INSPECT ASE
2.4 TRANSPORT ASE TO OTVPF
3.0 (REF) PERFORM OTV PROCESSING
3.3 MATE ASE TO OTV
3.1 MATE OTV TO FACILITY
GO TO 3.4

Figure 3-10. SBOTV Functional Flow: Shuttle/Centaur Type Facility

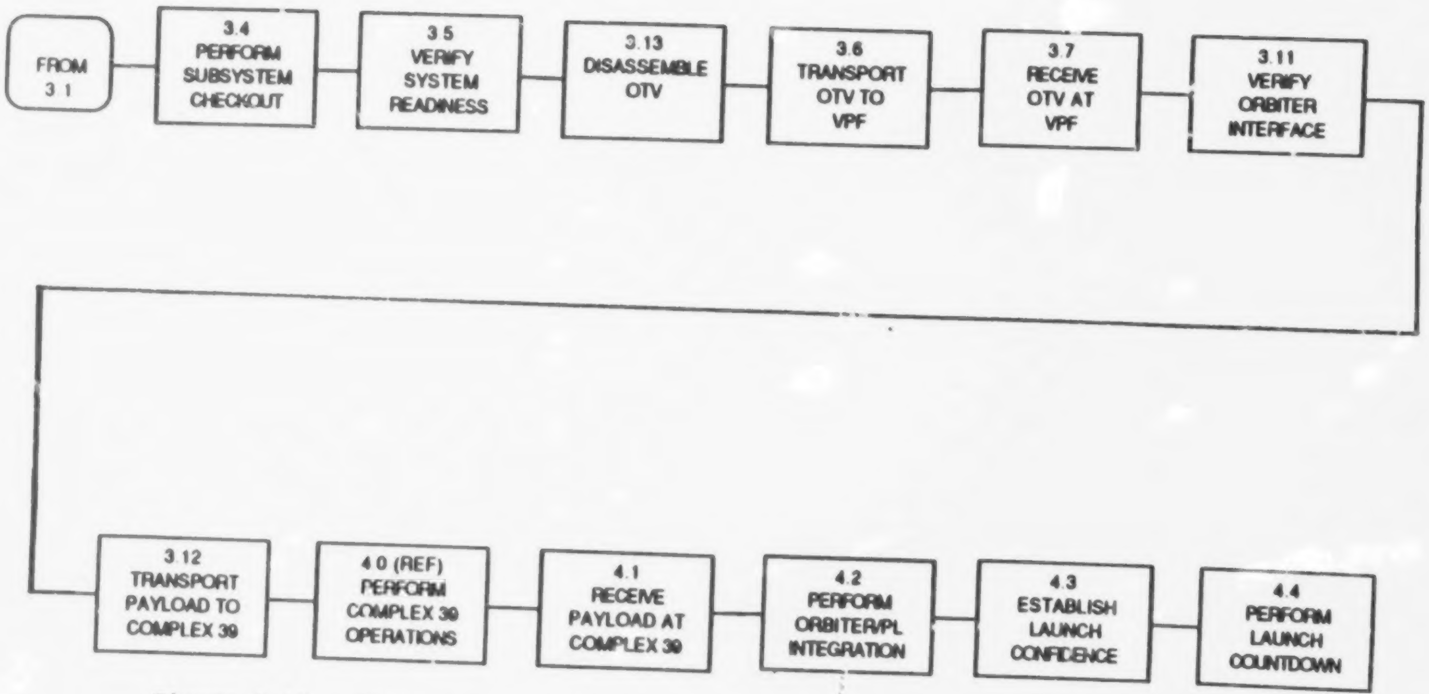

Figure 3-10. SBOTV Functional Flow: Shuttle/Centaur Type Facility, Contd

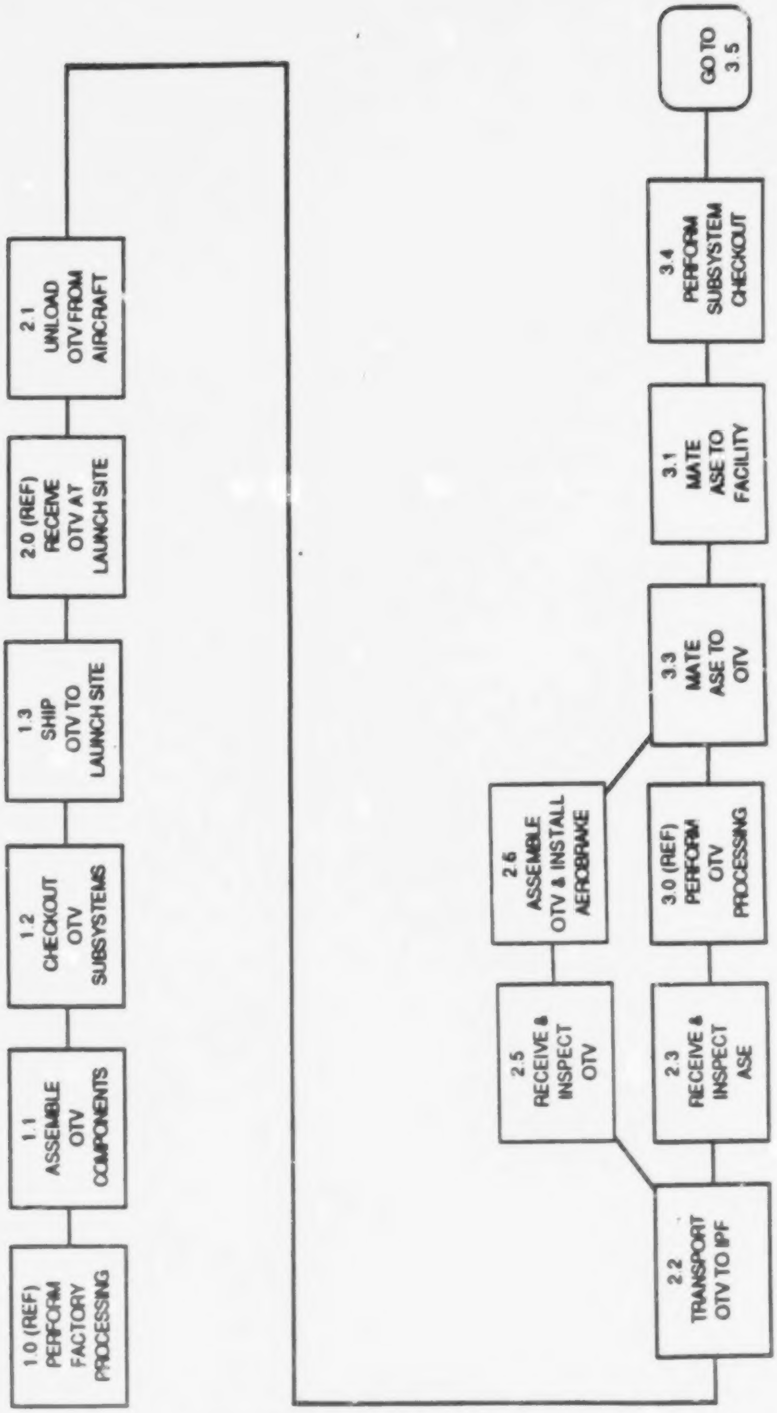
1.0 (REF) PERFORM FACTORY PROCESSING
1.1 ASSEMBLE OTV COMPONENTS
1.2 CHECKOUT OTV SUBSYSTEMS
1.3 SHIP OTV TO LAUNCH SITE
2.0 (REF) RECEIVE OTV AT LAUNCH SITE
2.1 UNLOAD OTV FROM AIRCRAFT
2.2 TRANSPORT OTV TO IPF
2.5 RECEIVE & INSPECT OTV
2.6 ASSEMBLE OTV & INSTALL AEROBRAKE
2.3 RECEIVE & INSPECT ASE
3.0 (REF) PERFORM OTV PROCESSING
3.3 MATE ASE TO OTV
3.1 MATE ASE TO FACILITY
3.4 PERFORM SUBSYSTEM CHECKOUT
GO TO 3.5

Figure 3-11. SBOTV Functional Flow: IPF

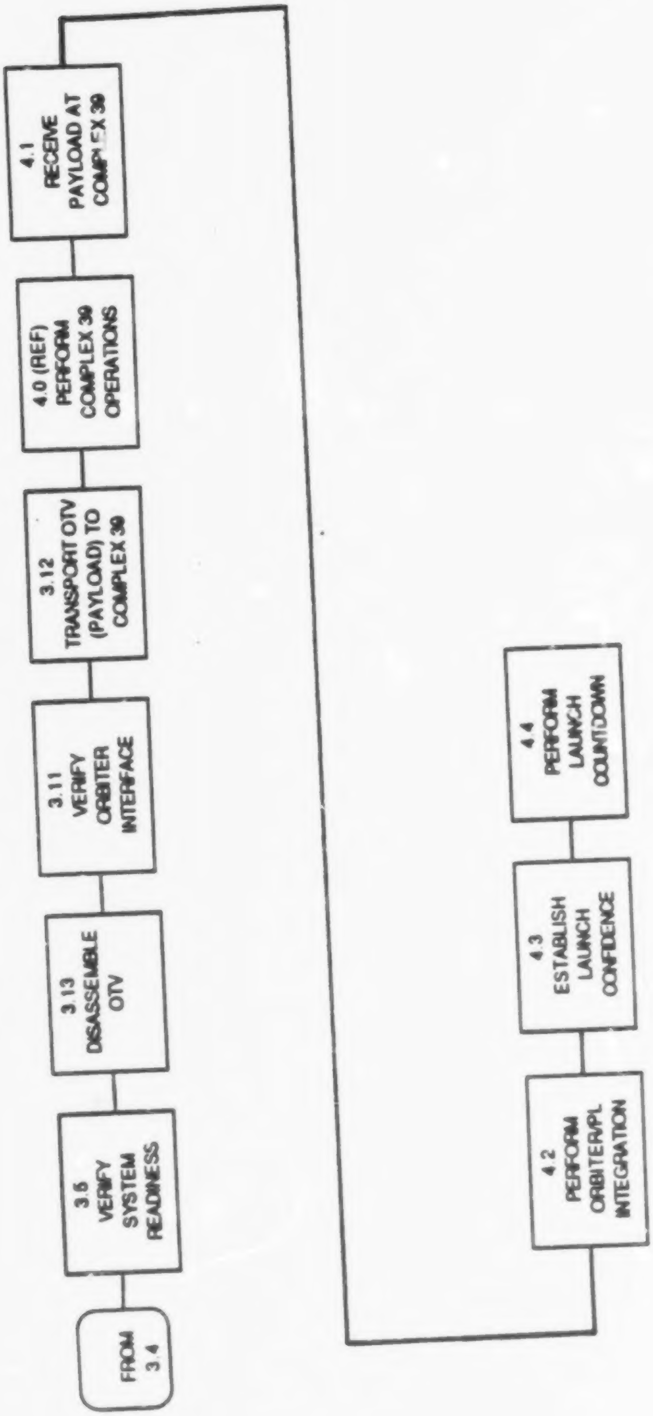
FROM 3.4
3.5 VERIFY SYSTEM READINESS
3.13 DISASSEMBLE OTV
3.11 VERIFY ORBITER INTERFACE
3.12 TRANSPORT OTV (PAYLOAD) TO COMPLEX 39
4.0 (REF) PERFORM COMPLEX 39 OPERATIONS
4.1 RECEIVE PAYLOAD AT COMPLEX 39
4.2 PERFORM ORBITER/PL INTEGRATION
4.3 ESTABLISH LAUNCH CONFIDENCE
4.4 PERFORM LAUNCH COUNTDOWN

Figure 3-11. SBOTV Functional Flow: IPF, Contd

3.4.4 MANPOWER ASSESSMENT/TIMELINES. This SBOTV timeline (Level 2) shown in Figure 3-12 reflects the ground processing time required to initially deliver the vehicle to its space-based accommodations. The vehicle is processed in facilities that are similar to those used by the Shuttle/Centaur. The timeline shows a single-shift operation and the elapsed time is 11 weeks and 1 day. Manpower requirements were generated in the same manner as previously discovered. Manpower requirements are shown in Table 3-11 for the two extreme options for facilities and tasks.

3.4.5 SBOTV GROUND OPERATIONS TRADE STUDY. Table 3-12 compares the facility and vehicle options for processing the SBOTV. The options are evaluated with the criteria listed in the left vertical column. The comparison resulted in a lower operations cost for a Shuttle/Centaur-type facility, which is the recommended option. The SBOTV is ground processed and launched only once every 40 missions. Therefore, this may be a shared facility.

The task description sheets contain data peculiar to each Level 2 task of the OTV turnaround. The task identification code and descriptor are the same as those used throughout the study. The purpose and a narrative description of the task are presented along with resource requirements, task duration and frequency. The resource requirements include the crew size and manhour requirements for the tasks in addition to the accommodations required to perform the tasks.

3.4.6 SBOTV GROUND PROCESSING RECOMMENDATIONS. Since the SBOTV is processed on the ground only once every 40 missions, the vehicle can be processed in a shared facility and at a more leisurely pace of a single-shift operation for the following reasons:

a. Interfaces/support equipment similar to Space Station.

b. Shared facility adequate for number of launches.

   1. Every 40 missions.

c. Candidate facilities.

   1. Launch Complex 36A.

   2. Cargo hazardous servicing facility.

d. Common control facility for both ground and space processing.

The facility can resemble the Shuttle/Centaur-type facility, although using a hazardous-cargo servicing facility would be a welcome improvement. The facility should simulate interfaces and support equipment similar to the Shuttle and the Space Station.

The new cargo hazardous processing facility shown in Figure 3-13 could be used as the SBOTV processing facility. This facility would allow processing in one location. The facility would accommodate the operational tasks of receiving inspection, cleaning, assembly, testing, maintenance and modifications, and storage. The facility would also provide cryo and reaction control system (RCS) loading capabilities.

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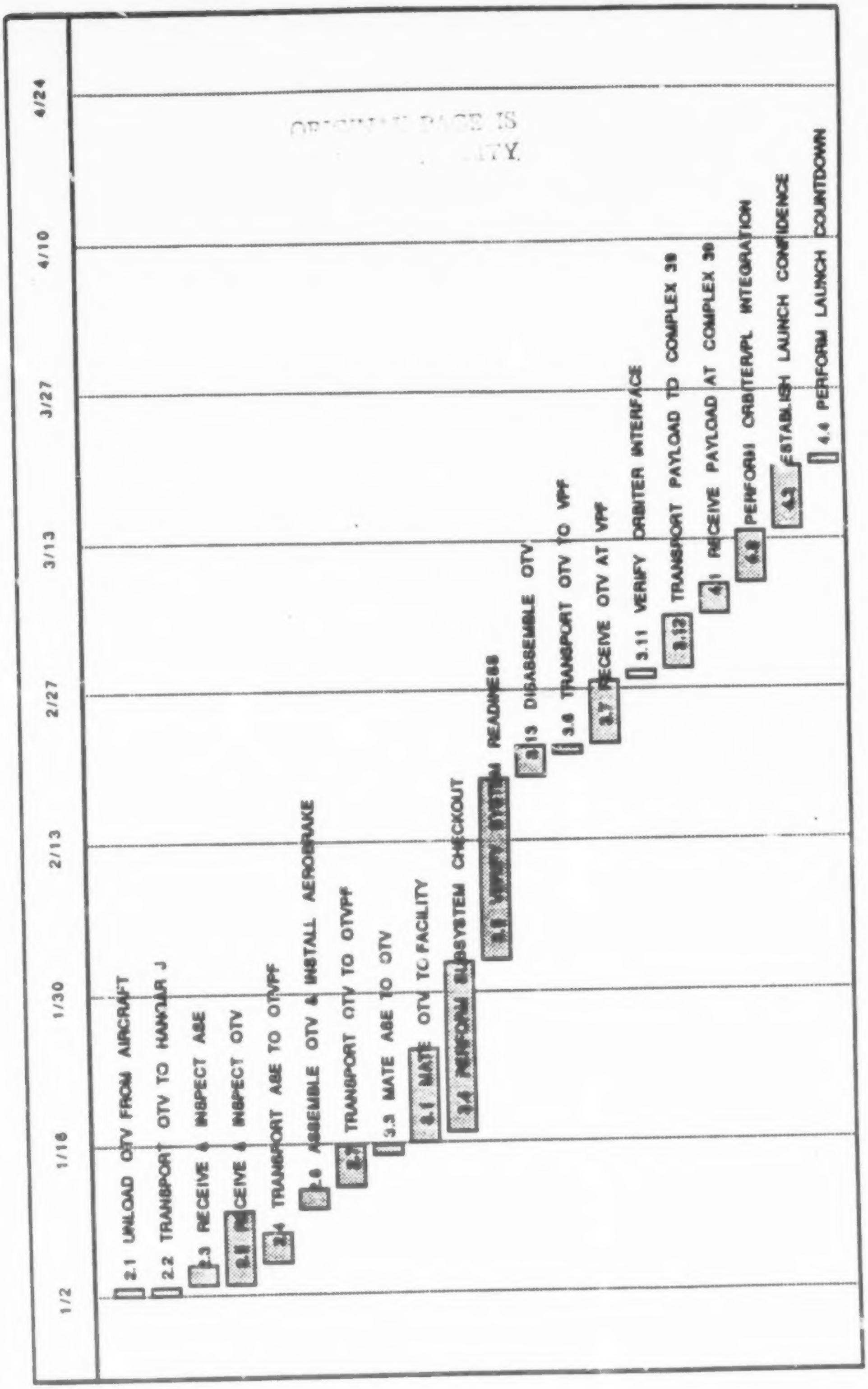

Figure 3-12. SBOTV Ground OPS Timeline: Shuttle/Centaur Type Facility, Full Vehicle Automation

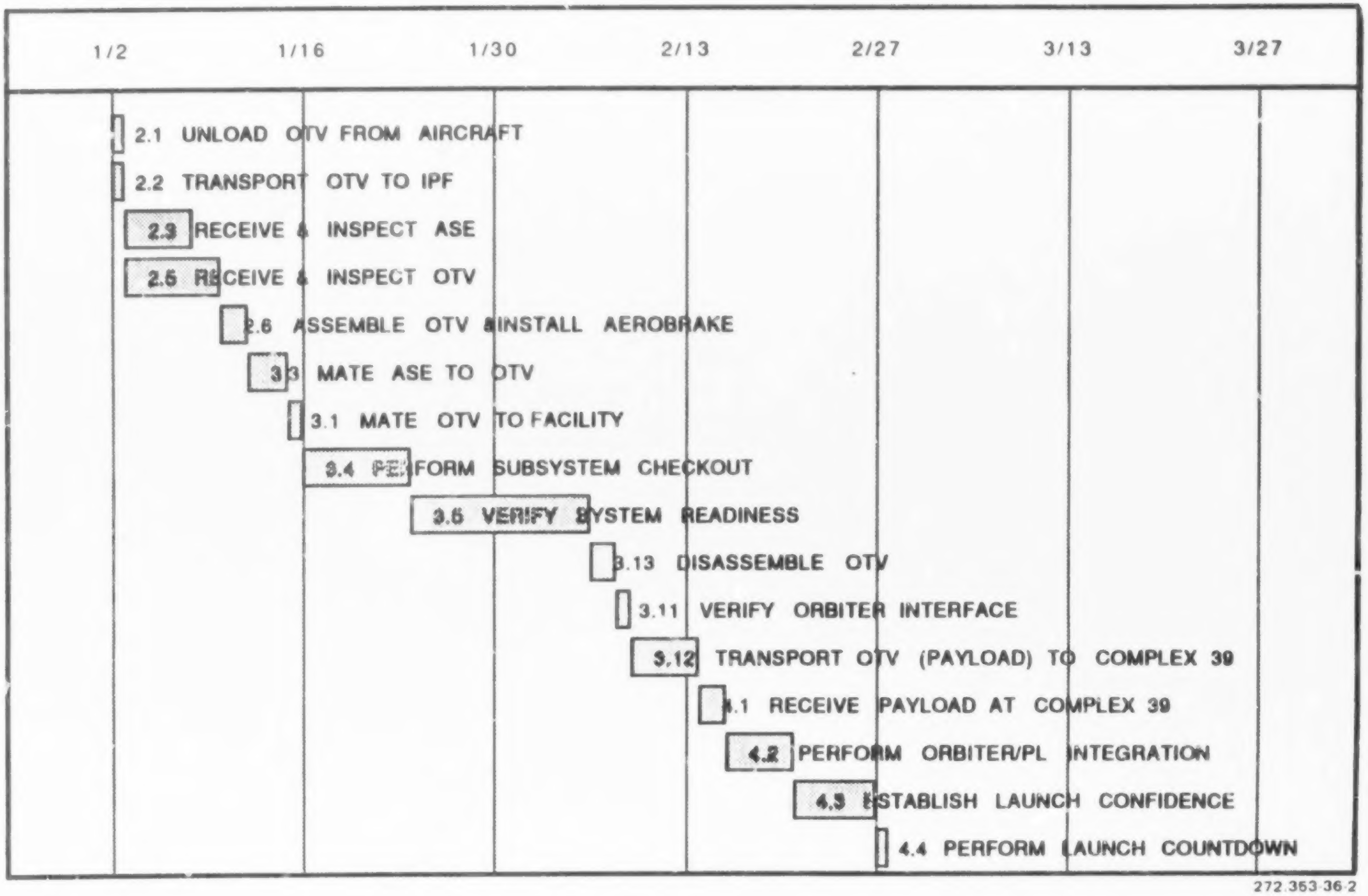

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Figure 3-12. SBOTV Ground OPS Timeline: Shuttle/Centaur Type Facility, Full Vehicle Automation, Contd

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS	
		S/C FACILITY S/C AUTO-MATION	INTEGRATED FAC. FULLY AUTOMATED
2.1	UNLOAD OTV FROM AIRCRAFT	72	72
2.2	TRANSPORT OTV TO HANGAR J/IPF	22	22
2.3	RECEIVE AND INSPECT ASE	32	32
2.4	TRANSPORT ASE TO OTVPF	44	--
2.5	OTV RECEIVE AND INSPECT	488	488
2.6	ASSEMBLE OTV AND INSTALL BALLUTE	208	208
2.7	TRANSPORT OTV TO OTVPF	--	--
3.1	MATE OTV TO FACILITY	784	320
3.2	PERFORM ASE SUBSYSTEM CHECKOUT	--	--
3.3	MATE ASE TO OTV	88	24
3.4	PERFORM SUBSYSTEM CHECKOUT	2074	1156
3.5	VERIFY SUBSYSTEM READINESS	3192	1564
3.13	DISASSEMBLE OTV	292	320
3.6	TRANSPORT OTV TO VPF	52	--
3.7	RECEIVE OTV AT VPF	304	--

1 2 (7/15)
272 353 37 1

Table 3-11. SBOTV Ground Manhour Requirements

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS	
		S/C FACILITY S/C AUTOMATION	INTEGRATED FAC. FULLY AUTOMATED
3.8	PREPARE OTV FOR SPACECRAFT MATING	--	--
3.9	MATE OTV AND SPACECRAFT	--	--
3.10	PERFORM OTV AND SPACECRAFT CHECKOUT	--	--
3.11	VERIFY ORBITER INTERFACE	136	96
3.12	TRANSPORT PAYLOAD TO CX39	408	408
4.1	RECEIVE PAYLOAD AT CX39	216	176
4.2	PERFORM ORBITER/PAYLOAD INTEGRATION	604	484
4.3	ESTABLISH LAUNCH CONFIDENCE	728	584
4.4	PERFORM LAUNCH COUNTDOWN	480	360
5.0	PERFORM OTV MISSION	--	--
6.0	PERFORM POST MISSION OPS	--	--
7.0	PERFORM MAINTENANCE & SERVICING	--	--
8.0	RECONFIGURE OTV FOR MISSION	--	--
	TOTAL MANHOURS	10332	6314

2-2 (7/15)
272.353-37-2

Table 3-11. SBOTV Ground Manhour Requirements, Contd

CRITERIA \ OPTION		S/C FACILITY WITH S/C AUTOMATION	INTEGRATED FACILITY WITH S/C AUTOMATION	S/C FACILITY FULLY AUTOMATED	INTEGRATED FULLY AUTOMATED
PROCESSING MANHOURS	INITIAL	NOT COMPATIBLE WITH		10,332	6,354
	TURNAROUND	SPACE STATION C/O			
VEHICLES/BAYS TO MEET MISSION LAUNCH SCHEDULE*				ONE BAY 8 VEHICLES	ONE BAY 8 VEHICLES
TOTAL MANHOURS x 10^3				72	44
MANHOUR COST ($M)				3	2
FACILITY COST ($M)				2	17
SUPPORT EQUIPMENT COST ($M)				37	37
COST ($M)**				42	56

SELECTED ✓

* DOES NOT CONSIDER MULTIPLE STAGES

** DIRECT VEHICLE OPERATIONS COSTS

Table 3-12. SBOTV Ground Operations Trade Study

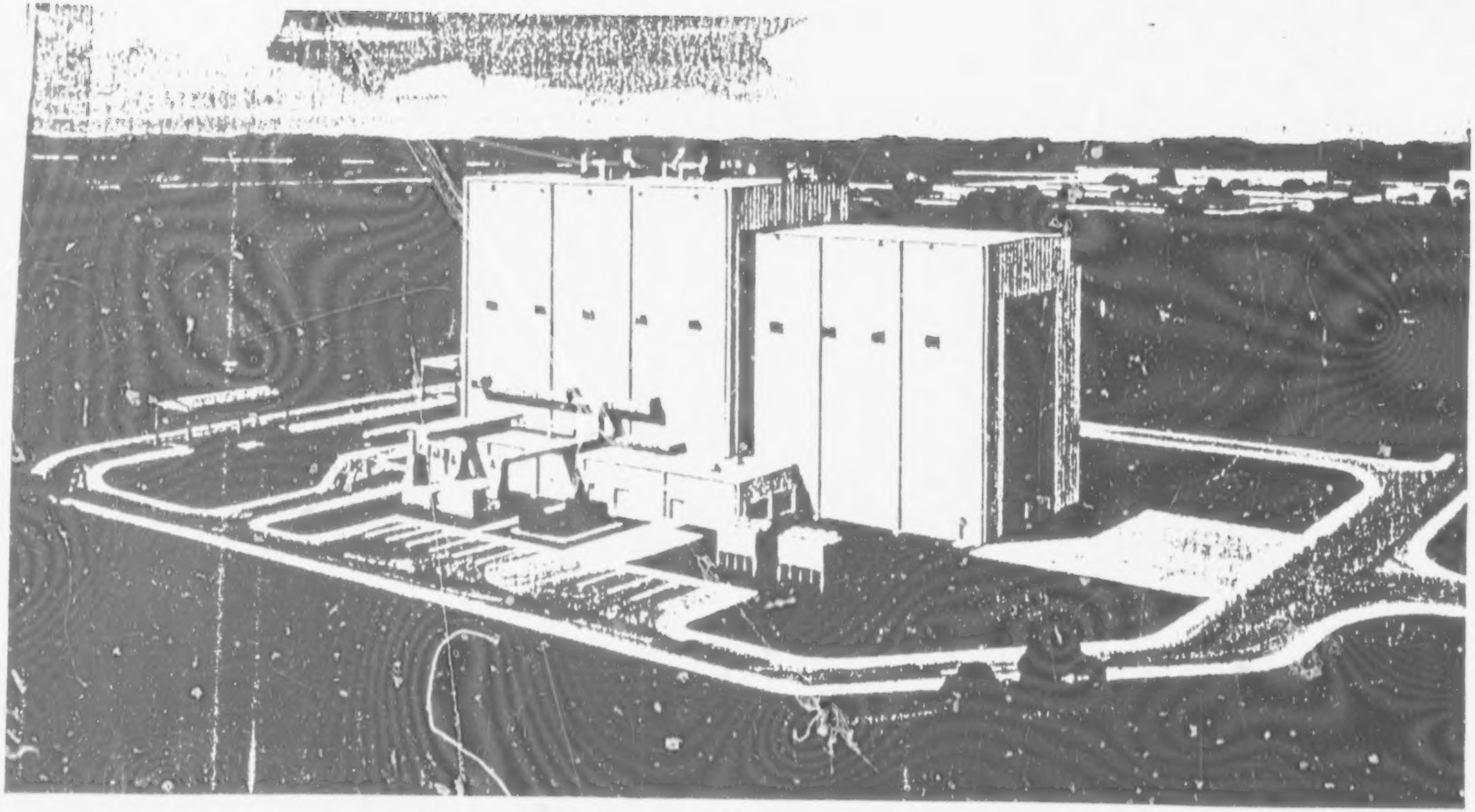

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Figure 3-13. Cargo Hazardous Servicing Facility (Proposed OTV Processing Facility)

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3.4.7 RECOMMENDED TASK DEFINITIONS. The task description sheets (see Table 3-13 as an example) contain data peculiar to each Level 2 task of the OTV turnaround. The task identification code and descriptor are the same as those used throughout the study. The purpose and a narrative description of the task are presented along with the resource requirements, task duration and frequency. The resource requirements include the crew size and manhour requirements for the tasks in addition to the accommodations required to perform the tasks.

3.5 UCV OTV

3.5.1 UCV OTV: MARTIN. The OTV concept that will be used for the follow-on task was developed by Martin and is shown in Figure 3-14.

The three-engine OTV design concept was developed for launch and return in a 25-foot-diameter large cargo vehicle (LCV). The tankage diameters were chosen such that the combined length of the liquid oxygen tanks and the retracted engines would be the same length as the liquid hydrogen tanks. This results in the shortest vehicle length to minimize launch costs per the charging algorithm. The short length allows use of a 32-foot-diameter aerobrake. The structure consists of a central core between the tanks that ties the tankage, aerobrake, and payload adapter together. This assembly remains as a unit after the mission when the aerobrake is jettisoned. If the LCV does not have the capability to return the OTV to earth after the mission, the OTV will be disassembled for return in the STS payload bay. The high-volume, low-cost cryogenic tanks are removed and the structural core is returned to earth with the high costs unit items such as main engines, power system, avionics, RCS, etc.

3.5.2 UCV OTV PROCESSING REQUIREMENTS. The processing requirements were obtained in the same manner as the cargo bay GBOTV (see Section 3.1.2) except that the UCV OTV does not go on the Shuttle but on an UCV.

Table 3-14 is an example of how we surveyed the Shuttle/Centaur processing tasks to see if they are applicable for the OTV. A "Y" in the "GBOTV Use Y/N" column designates applicability for OTV. Each task that is applicable to UCV OTV ground processing is incorporated into the analyses and adequately referenced to provide traceability back to the original Shuttle/Centaur data base. Table 3-15 lists the top-level requirements for the UCV turnaround operations.

3.5.3 FUNCTIONAL FLOWS. Figure 3-15 is a Level 2 functional flow diagram of the UCV GBOTV, which is processed using Shuttle/Centaur-type facilities. The flow includes factory processing, initial processing, and turnaround operations. Factory processing is shown here, because the baseline Shuttle/Centaur data included some of these functions. The factory processing functions have been identified and are deleted from OTV operations analyses.

The initial processing of the vehicle begins by unloading the OTV from the delivery aircraft (2.1) and ends when the vehicle is launched (4.4).

Turnaround operations include all of the initial processing functions except 2.1, and adds functions 5.0 through 8.0 to the flow. During turnaround operations, the ASE and vehicle will be checked out only to the extent

TASK-IDENT	DESCRIPTOR
3.3	MATE ASE TO OTV

PURPOSE

MATE ASE TO OTV TO PREPARE FOR ORBITER MANIFEST AND SUBSYSEM TEST

TASK DESCRIPTION

ASE FINAL PREPARATIONS FOR MATE. MATE ASE TO OTV. PREPARE FOR SUBSYSTEM TEST.

TASK DURATION
24 HOURS (3 DAYS)

TASK FREQUENCY
INITIAL DELIVERY TO LAUNCH SITE
ONCE EVERY FORTY MISSIONS

SOURCE REQUIREMENTS

CREW

	CREW SIZE	MANHOURS
ENGINEERS	7	76
MECHANICS	16	160
TECHNICIANS		
INSPECTORS	5	60
POWER CREW		
TOTAL	28	296

ACCOMMODATIONS
IPF
HANDLING/LIFTING EQUIPMENT
CRANE

SPARES

OTHER VEHICLE SYSTEMS AFFECTED

Table 3-13. Task Description Sheet: Ground Processing - Space Based - IPF

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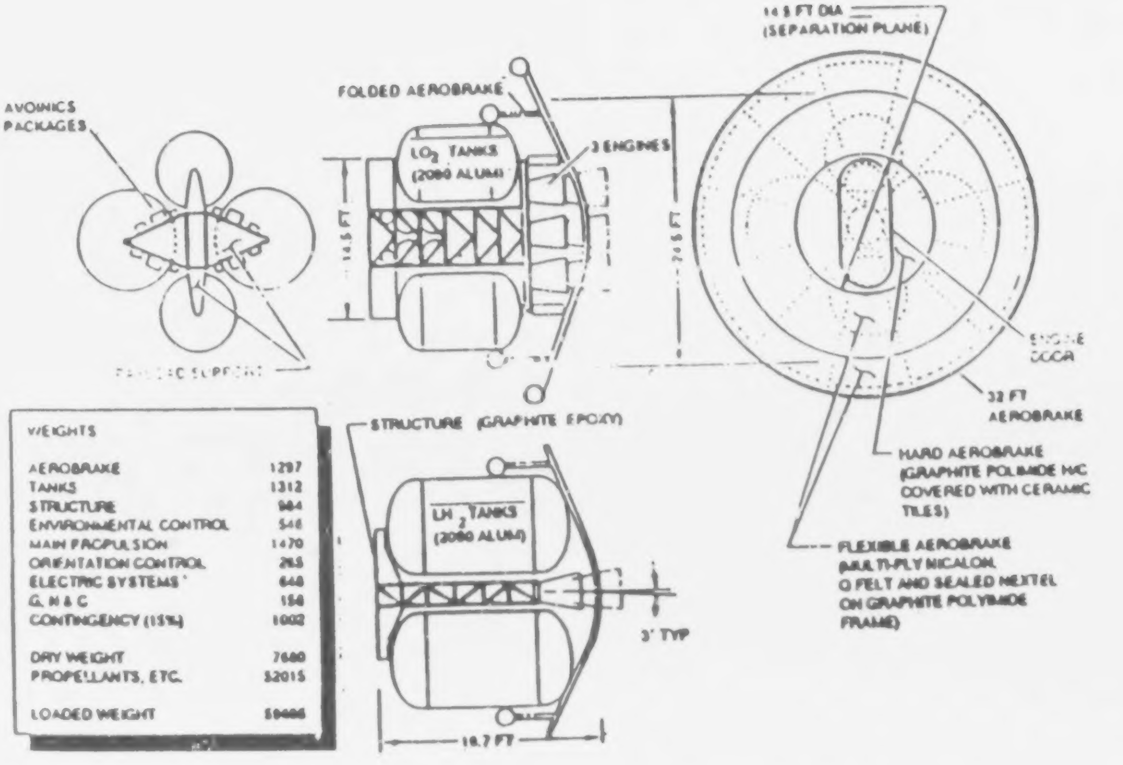

WEIGHTS	
AEROBRAKE	1297
TANKS	1312
STRUCTURE	984
ENVIRONMENTAL CONTROL	546
MAIN PROPULSION	1470
ORIENTATION CONTROL	265
ELECTRIC SYSTEMS	648
G, N & C	156
CONTINGENCY (15%)	1002
DRY WEIGHT	7680
PROPELLANTS, ETC.	52015
LOADED WEIGHT	59695

Figure 3-14. UCV OTV: Martin

TASK NUMBER	TASK DESCRIPTION	PROCEDURES	GBROTV USE Y/N	COMMENTS/RATIONALE
1.1	UNLOAD CENT/CISS FROM ACFT		Y	
1.2(REF)	RCV & INSP CISS		Y	
1.2.1	CISS PREPOWER I/F TEST	NET-9005	Y	
1.2.2	CISS STD TURN-ON PROFILE	NET-9007	Y	
1.2.3	CISS AV SUBSYS FCTN CO	NET-9000	N	
1.2.4	CISS PRESS SYS FCTN CO	PNEU-9005	N	
1.2.5	CISS VENT SYS CO	PNEU-9007	N	
1.2.6	CISS PAVCS FCTN CO	PNEU-9006	N	
1.2.7	CISS PURGE SYS CHKS	PNEU-9015	N	
1.2.8	CISS MECH RCV & INSP	MECH-9001	Y	
1.2.9	CISS ELEC RCV & INSP	NET-9001	N	
1.2.10	CISS INSTRU RCV & INSP	TLM-9003	N	
1.2.11	CISS PWR-OFF XDCR RING-OUT	TLM-9005	N	
1.2.12	CISS PWR-ON XDCR RING-OUT	TLM-9005	N	FACTORY PROCESSING
1.2.13	CISS PNEU SYS RCVG PREPS	PNEU-9019	N	FACTORY PROCESSING
1.3	XPORT CISS TO CX36A	STR-9002	Y	
1.4(REF)	CENT RCV & INSP		Y	
1.4.1	CENT N2H4 SYS THR PRESS	N2H4-9004	N	
1.4.2	CENT MECH RCV & INSP	MECH-9000	Y	
1.4.3	CENT CRYO FLG BOLT TRQ CHK	PROP-9002	N	
1.4.4	CENT PROP/HYD RCVG PREPS	PROP-9001PRE-BLKT	Y	
1.4.5	CENT FILL & DRAIN CO	FLU-9001	N	
1.4.6	CENT PROP/HYD RCVG PREPS	PROP-9001	N	
1.4.7	CENT PNEU SYS RCVG PREPS	PNEU-9019	Y	
1.4.8	CENT PROP TK PRG & SMPLG	PNEU-9002	Y	
1.4.9	CENT VENT SYS FCTN CHKS	STR-9011	N	
1.4.10	PREP CENT/PLL FOR XFER	STR-9001	Y	
1.4.11	CENT RCV & INSP ELEC	NET-9002	Y	
1.4.12	CENT LO2 LH2 PROBE & CABLE	NET-9003	Y	FACTORY PROCESSING
1.5	XPORT CENT & PLL TO CX36A	STR-9001	Y	
2.1	MATE CISS TO CX36A	STR-9010	Y	
2.2(REF)	PREP CISS FOR CENT MATING		Y	

SSD6046

Table 3-14. Shuttle/Centaur to UCV GBOTV Processing Correlations

1.0 POSTLANDING OPERATIONS:
  R1 SAFE OTV PRIOR TO TRANSFER TO THE OPF.

2.0 TRANSFER OTV TO PROCESSING FACILITY:

3.0 RECEIVE AND INSPECT RETRIEVAL ASE AND OTV:
  R3 INSPECT ASSEMBLIES FOR FLIGHT DAMAGE.
  R5 INSTALL RETRIEVAL ASE IN ORBITER.

4.0 MATE OTV TO FACILITY:
  MECHANICAL AND ELECTRICAL MATE. MAY INCLUDE NUMEROUS FLUID INTERFACES.
  R7 VERIFY ALL INTERFACES.

5.0 OTV SUBSYSTEM CHECKOUT:
  R6 VERIFY READINESS OF OTV SUBSYSTEMS FOR COMBINED SYSTEM FUNCTIONAL TEST.

6.0 OTV MAINTENANCE:
  REMOVE AND REPLACE COMPONENTS AS REQUIRED BY SUBSYSTEM TEST OR FLIGHT PERFORMANCE. RETEST AS REQUIRED.

7.0 COMBINED SYSTEMS FUNCTIONAL TEST:
  R9 VERIFY OTV FULLY OPERATIONAL AND FLIGHT READY PRIOR TO TRANSFER TO THE LAUNCH PAD.

Table 3-15. UCV GBOTV Level 1 Requirements: Turnaround Operations

8.0 TRANSFER TO LAUNCH PAD:
R13 OTV FLIGHT READY.
INCLUDES MECHANICAL MATE TO UCV AND MECHANICAL/ELECTRICAL MATE TO THE LAUNCH PAD.
R11 VERIFY OTV - PAD AND OTV - UCV INTERFACES.

9.0 MATE SPACECRAFT TO OTV:
R14 OTV, UCV AND SPACECRAFT FLIGHT READY.
INCLUDES SPACECRAFT MECHANICAL AND ELECTRICAL MATE TO THE OTV.

10.0 INTERFACE VERIFICATION TESTS:
R12 VERIFY INTERFACES BETWEEN SPACECRAFT - OTV.

11.0 LAUNCH CONFIDENCE TEST:
R15 VERIFY LAUNCH READINESS OF OTV, SPACECRAFT, AND UCV SYSTEMS PRIOR TO LAUNCH.
R16 TURNAROUND MAY INCLUDE TANKING OF OTV IF REQUIRED BY SYSTEM MAINTENANCE.

12.0 LAUNCH OPERATIONS:
INCLUDES COORDINATED OTV AND UCV TANKING OPERATIONS.

Table 3-15. UCV GBOTV Level 1 Requirements: Turnaround Operations, Contd

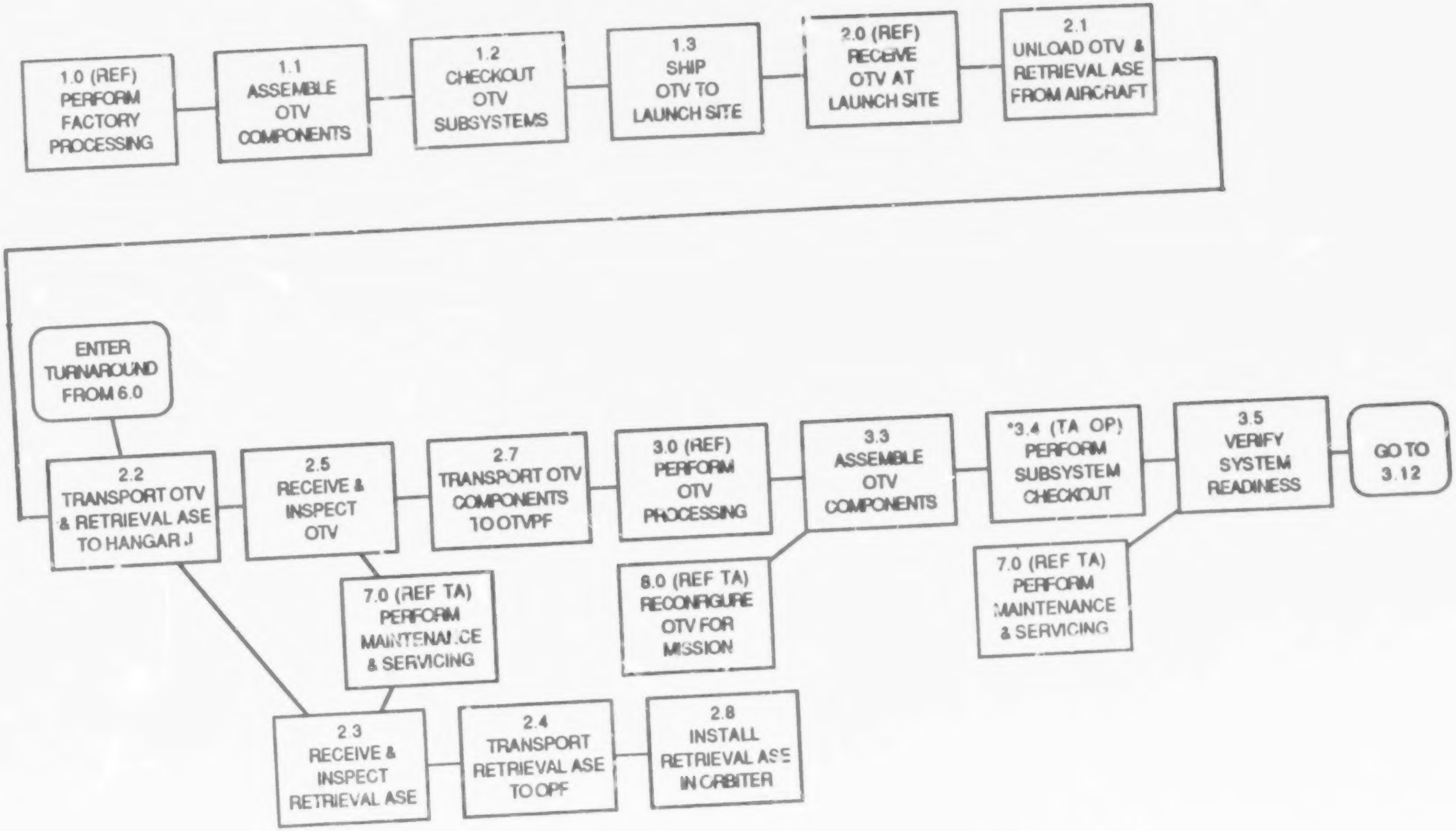

Figure 3-15. UCV GBOTV Functional Flow: Shuttle/Centaur Type Facility

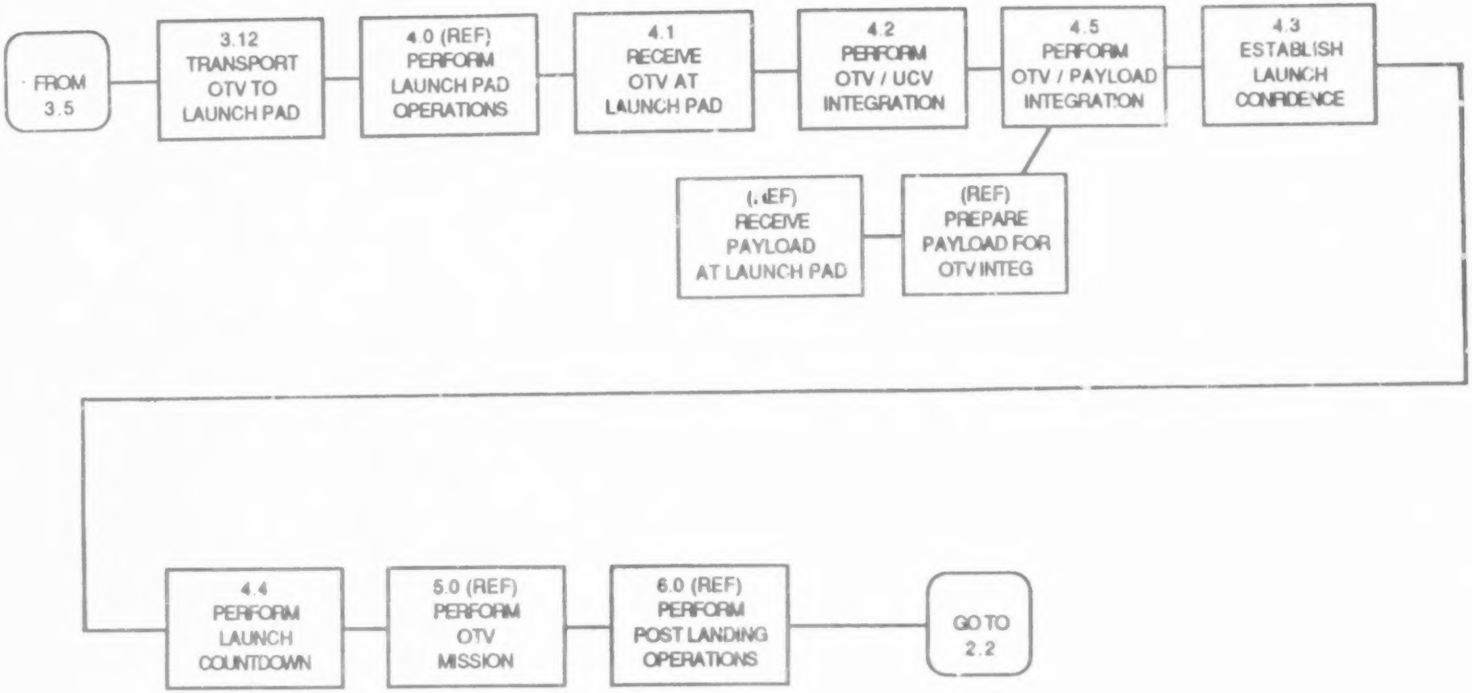
FROM 3.5
3.12 TRANSPORT OTV TO LAUNCH PAD
4.0 (REF) PERFORM LAUNCH PAD OPERATIONS
4.1 RECEIVE OTV AT LAUNCH PAD
4.2 PERFORM OTV / UCV INTEGRATION
4.5 PERFORM OTV / PAYLOAD INTEGRATION
4.3 ESTABLISH LAUNCH CONFIDENCE
(REF) RECEIVE PAYLOAD AT LAUNCH PAD
(REF) PREPARE PAYLOAD FOR OTV INTEG
4.4 PERFORM LAUNCH COUNTDOWN
5.0 (REF) PERFORM OTV MISSION
6.0 (REF) PERFORM POST LANDING OPERATIONS
GO TO 2.2

Figure 3-15. UCV GBOTV Functional Flow: Shuttle/Centaur Type Facility, Contd

necessary. The amount of checkout required will be determined by flight data analysis, and maintenance/reconfiguration performed. An asterisk in front of the functional number denotes those functions that would be affected by checkout requirements.

Figure 3-16 is a Level 2 functional flow diagram of the UCV GBOTV, which is processed using an IPF. The flow includes factory processing, initial processing, and turnaround operations. Factory processing is shown here, because the baseline Shuttle/Centaur data included some of these functions. The factory processing functions have been identified and are deleted from OTV operations analyses.

The initial processing of the vehicle begins by unloading the OTV from the delivery aircraft (2.1) and ends when the vehicle is launched (4.4).

Turnaround operations include all of the initial processing functions except 2.1, and adds functions 5.0 through 8.0 to the flow. During turnaround operations, the ASE and vehicle will be checked out only to the extent necessary. The amount of checkout required will be determined by flight data analysis, and maintenance/reconfiguration performed. An asterisk in front of the functional number denotes those functions that would be affected by checkout requirements.

3.5.4 MANPOWER ASSESSMENT/TIMELINES. Timelines and manpower requirements for the UCV OTV were generated in a similar manner as the cargo bay OTV (see Section 3.1.4).

Table 3-16 is a sample of a task analysis worksheet. The task analysis worksheet for ground processing contains the basic data acquired from the Shuttle/Centaur program as well as new tasks identified as appropriate for OTV processing. The worksheet identifies the OTV task number and lists the corresponding Shuttle/Centaur task number from that data base to provide adequate traceability. New OTV tasks register a blank in the Shuttle/Centaur tasks number column. The tasks reflect the ground processing activities down to Level 3.

Figure 3-17 is a Level 2 timeline for the UCV GBOTV initial processing within a Shuttle/Centaur-type facility and Shuttle/Centaur level of vehicle automation, showing that it takes 13 weeks and 3 days for a single-shift operation. Increasing to a double-shift, 5-day work week, which is what was used for facility sizing and overall analysis, reduces this figure to 6 weeks, and 4 days for initial processing.

The Level 2 turnaround time shown on Figure 3-18 for the UCV GBOTV using a Shuttle/Centaur-type facility and Shuttle Centaur level of vehicle automation. The timeline is based on a single-shift operation. The elapsed time can be reduced by going to a double-shift, 5-day work week, which was used for facility sizing and overall analysis. The elapsed time for the double shift and a minimum turnaround is 6 weeks, 2 days. A 5-day mission was assumed in our analyses.

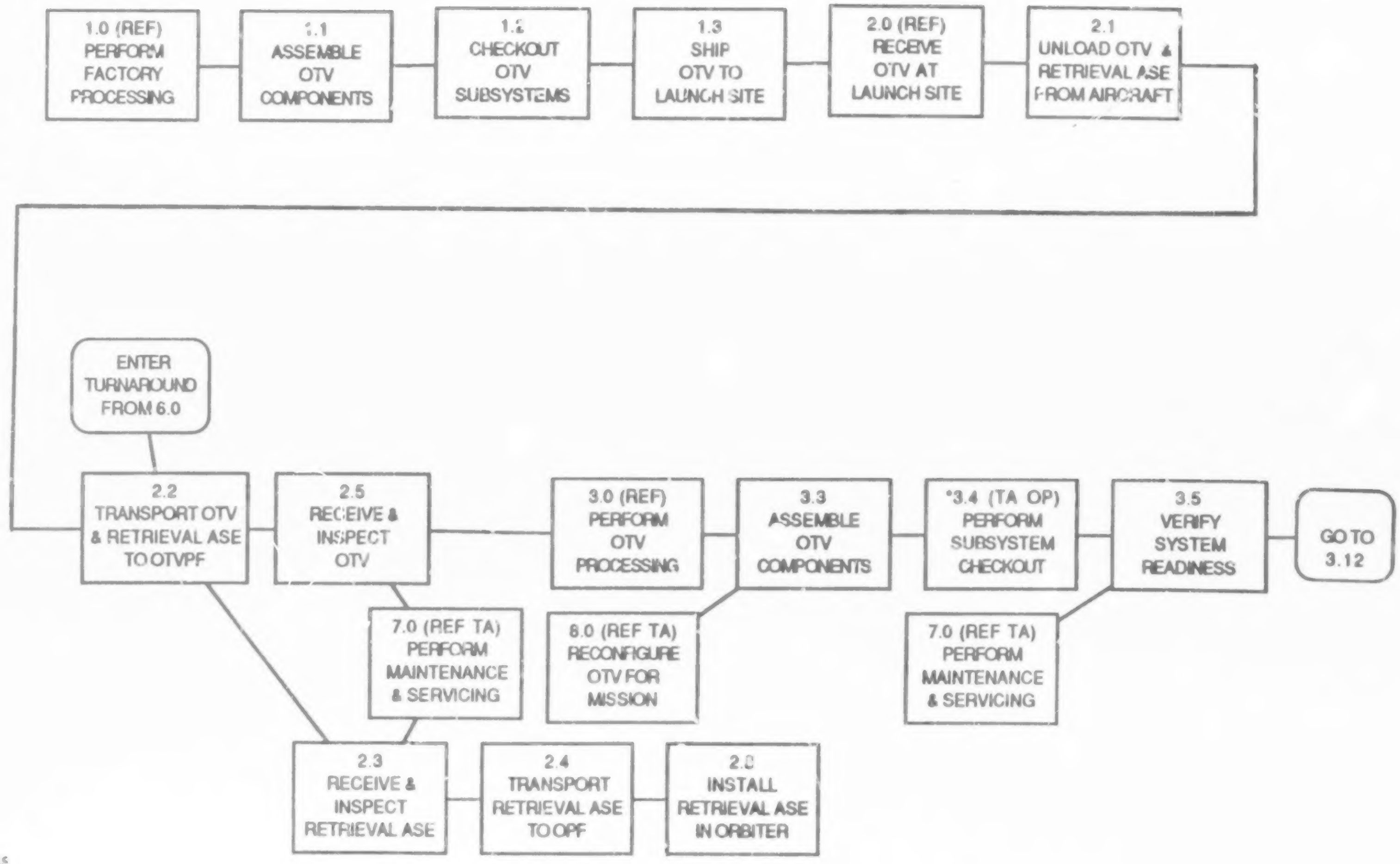
1.0 (REF) PERFORM FACTORY PROCESSING
1.1 ASSEMBLE OTV COMPONENTS
1.2 CHECKOUT OTV SUBSYSTEMS
1.3 SHIP OTV TO LAUNCH SITE
2.0 (REF) RECEIVE OTV AT LAUNCH SITE
2.1 UNLOAD OTV & RETRIEVAL ASE FROM AIRCRAFT
ENTER TURNAROUND FROM 6.0
2.2 TRANSPORT OTV & RETRIEVAL ASE TO OTVPF
2.5 RECEIVE & INSPECT OTV
7.0 (REF TA) PERFORM MAINTENANCE & SERVICING
2.3 RECEIVE & INSPECT RETRIEVAL ASE
2.4 TRANSPORT RETRIEVAL ASE TO OPF
2.6 INSTALL RETRIEVAL ASE IN ORBITER
3.0 (REF) PERFORM OTV PROCESSING
3.3 ASSEMBLE OTV COMPONENTS
8.0 (REF TA) RECONFIGURE OTV FOR MISSION
*3.4 (TA OP) PERFORM SUBSYSTEM CHECKOUT
3.5 VERIFY SYSTEM READINESS
7.0 (REF TA) PERFORM MAINTENANCE & SERVICING
GO TO 3.12

Figure 3-16. UCV GBOTV Functional Flow: IPF

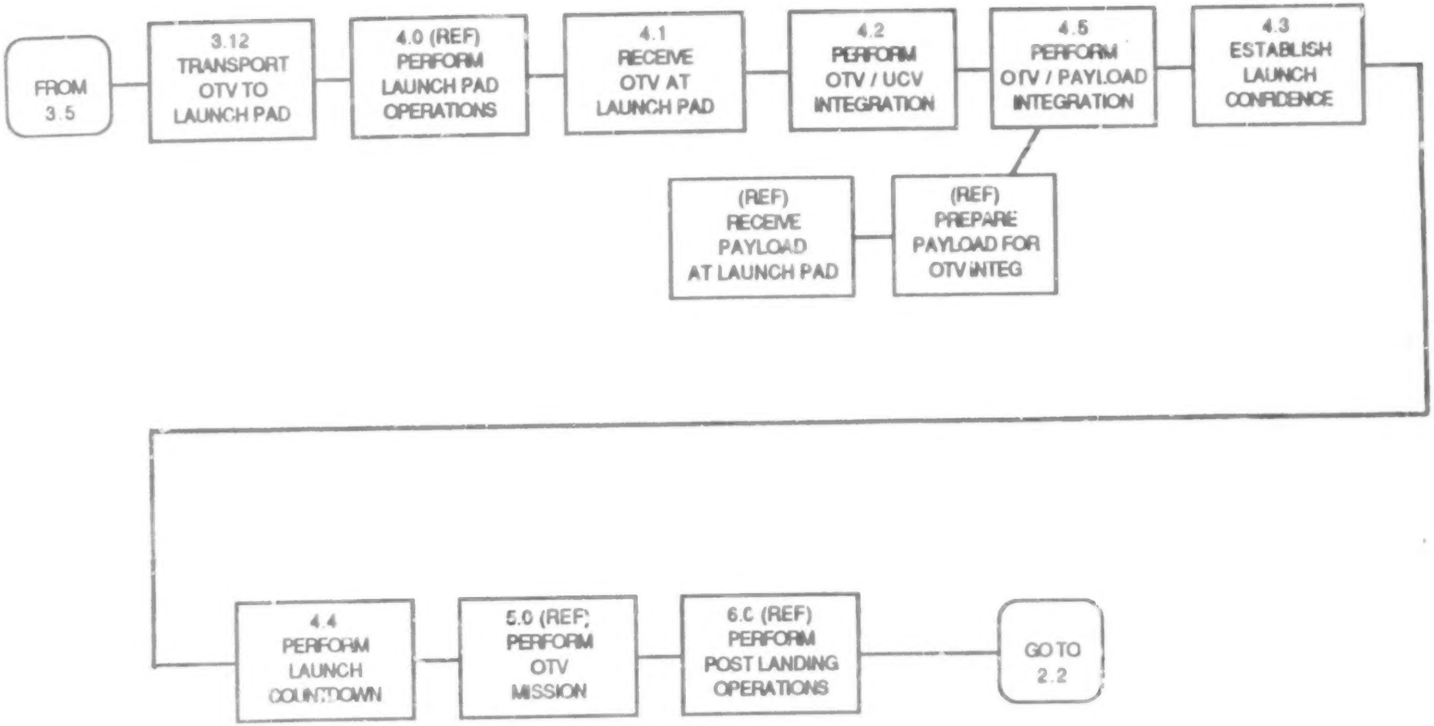

Figure 3-16. UCV GBOTV Functional Flow: IPF

Figure 3-19 is a Level 2 timeline for the UCV GBOTV initial processing within an IPF and full vehicle automation, showing that it takes 9 weeks and 6 days for a single-shift operation. Increasing to a double-shift, 5-day work week, which is what is what was used for facility sizing and overall analysis reduces this figure to 4 weeks and 6 days for initial processing.

The Level 2 turnaround time shown in Figure 3-20 is for the UCV GBOTV using an IPF and full vehicle automation. The timeline is based on a single-shift operation. The elapsed time can be reduced by going to a double-shift 5-day work week, which was used for facility sizing and overall analysis. The elapsed time for the double-shift and a minimum turnaround is 5 weeks and 1 day. A 5-day mission was assumed in our analyses.

Table 3-17 shows a summary of manhours required to process an UCV OTV. It presents the two extreme options: 1) Shuttle/Centaur-type facility with Shuttle/Centaur level of automation and 2) the IPF with full vehicle automation, for both initial processing and turnaround processing.

Only Level 2 tasks are presented in this summary to clearly shown which tasks are needed for each option and how many manhours are expended. An overall total is provided at the bottom of the chart, which allows comparison of each option. The manhours for turnaround are minimum values plus 120 manhours for the maintenance, servicing, and reconfiguration functions.

Table 3-18 is a manpower summary for the options, including initial and turnaround processing manhours, average and peak crew requirements per shift, the number of shifts required, and the elapsed time for a double-shift 5 day work week. The turnaround manhours are broken down to three values: minimum, maximum, and nominal. The minimum value does not include any of the optional turnaround tasks. It is assumed that the vehicle returns from a mission without faults and does not need preventive maintenance or reconfiguration. The maximum manhours includes all of the optional tasks. It assumes total testing is required as in the initial processing operations. The same amount as initial processing. This means that all subsystems are fully checked and that a full-up terminal countdown with cryogenic propellant loading is required. The nominal figure is derived from the reliability estimate which established the amount of maintenance required and reconfiguration estimates as a result of mission model assessments. The nominal manhours are estimated to be about 10% of the optional task manhours added to the minimum manhours.

The peak crew requirements show all personnel needed to support intense parallel operations such as launch countdown. The average crew required may be supplemented by factory people during these parallel operations.

3.5.5 TRADES. Table 3-19 compares the facility and vehicle options for processing the UCV GBOTV. The options are evaluated with the criteria listed in the left vertical column. The comparison resulted in a lower operations cost for an IPF combined with a fully automated vehicle, which is the recommended option.

Table 3-20 shows the comparison of the manpower requirements for the recommended approach for the cargo bay OTV and the UCV OTV and where the differences are.

OTV TASK NUMBER	SHUTTLE/CENTAUR TASK NUMBER	TASK DESCRIPTION	PROCEDURES	PERSONNEL REQUIRED					LOCATION		TEAM	TASK TIME (HRS)	MANHOURS (HRS)	MANHOUR OPTIONAL TASK	SECOND LEVEL MH REQ
				ENG	MECH	TECH	INSP	PWR	IPF	39A					
3.2.5	2.2.10	INSTL OTV/FAC FLUID LINES	PNEU-9003	2	4		1		X		FLUID	8	56		
3.4.3	2.4.18	CRYO FLG BOLT TRQ CHKS	PROP-9002	1	3		1		X		PROP	8	40		
3.4.3	2.4.18	CRYO FLG BOLT IWU CHKS	PROP-9002	1	3		1		X		FLUID	8	40		
* 3.4.4	2.4.27 PART3	RF SYS CO	RF-9000	1		2	1		X		RF-INSTR	8	32		
* 3.4.4	2.4.27 PART3	RF SYS CO	RF-9000					5	X		PWR	(8)	0		
3.4.30(NEW)	2.4.27 PART1	C-BAND DEACON CO	RF-3005(ATLAS)	1		2	1		X		RF-INSTR	4	16		
3.4.30(NEW)	2.4.27 PART1	C-BAND BEACON CO	RF-3005(ATLAS)					5	X		PWR	4	20		
3.4.31(NEW)	2.4.27 PART2	RANGE SAFETY SYSTEM CO	RCS-3001(ATLAS)	1		2	1		X		RF-INSTR	4	16		
3.4.31(NEW)	2.4.27 PART2	RANGE SAFETY SYSTEM CO	RCS-3001(ATLAS)					5	X		PWR	4	20		
* 3.4.8	2.4.4	OTV PAVCS SYS CO	PNEU-9010	1	2		1		X		PNEU	8		32	
* 3.4.8	2.4.4	OTV PAVCS SYS CO	PNEU-9010					5	X		PWR	(8)		0	
* 3.4.9	2.4.5	OTV VENT SYS FNTC CO	PNEU-9011	1	1				X		PNEU	4		8	
* 3.4.9	2.4.5	OTV VENT SYS FNTC CO	PNEU-9011					5	X		PWR	(4)		0	
* 3.4.10	2.4.6	OTV PRESS SYS FNTC CO	PNEU-9009	1	1		1		X		PNEU	12		36	
* 3.4.10	2.4.6	OTV PRESS SYS FNTC CO	PNEU-9009					5	X		PWR	12		60	
* 3.4.11	2.4.7	OTV HE STOR PRESS	PNEU-9004	1	2		1		X		PNEU	8		32	
* 3.4.11	2.4.7	OTV HE STOR PRESS	PNEU-9004					5	X		PWR	(8)		0	
3.4.12	2.4.17	VRFY PROP SYS READY TEST	PROP-9004	2	4		2		X		PROP	4	32		
3.4.13	2.4.9	VERFY PNEU RDNS	PNEU-9013	2	4		2		X		PNEU	8	64		
3.4.32(NEW)		AEROBRAKE SYSTEM CO		1	1		1		X		STR	4	12		
3.4.32(NEW)		AEROBRAKE SYSTEM CO		1		1	1		X		ELEC	4	12		
3.4.32(NEW)		AEROBRAKE SYSTEM CO						5	X		PWR	4	20		
* 3.4.15	2.4.38	ACTIVATE OTV ELEC PWR SYS	MET-9012	1		2	1		X		ELEC	16		64	
3.4.17	2.4.40	AVONICS SUBSYS VERIF	MET-9021	1		1	1		X		ELEC	4	12		
3.4.17	2.4.40	AVONICS SUBSYS VERIF	MET-9021					5	X		PWR	4	20		
* 3.4.18	2.4.46	OTV PURGE SYS CO	PNEU-9017	1	2		1		X		PNEU	8		32	
* 3.4.18	2.4.46	OTV PURGE SYS CO	PNEU-9017					5	X		PWR	8		40	
3.4.24	2.4.56	VRFY OTV STRUCT OPS	STR-9012	1	4		1		X		STR	8	48		
3.4.25	2.4.57	PREP STRUCT FOR SYS TEST	STR-9011	1	4		2		X		STR	8	56		
3.4.28	2.4.64	FACILITY ELEC RDNS CHKS	FE-9000	1		1	1		X		FAC ELEC	8	24		
3.4.29	2.4.66	OTV ELEC RDNS CHKS	MET-9022	1		2	2		X		ELEC	12	60		
3.5(REF)		VERIFY SYSTEM READINESS										-	0		642

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Table 3.16. UCV GBOTV Turnaround Processing: IPF, Full Automation

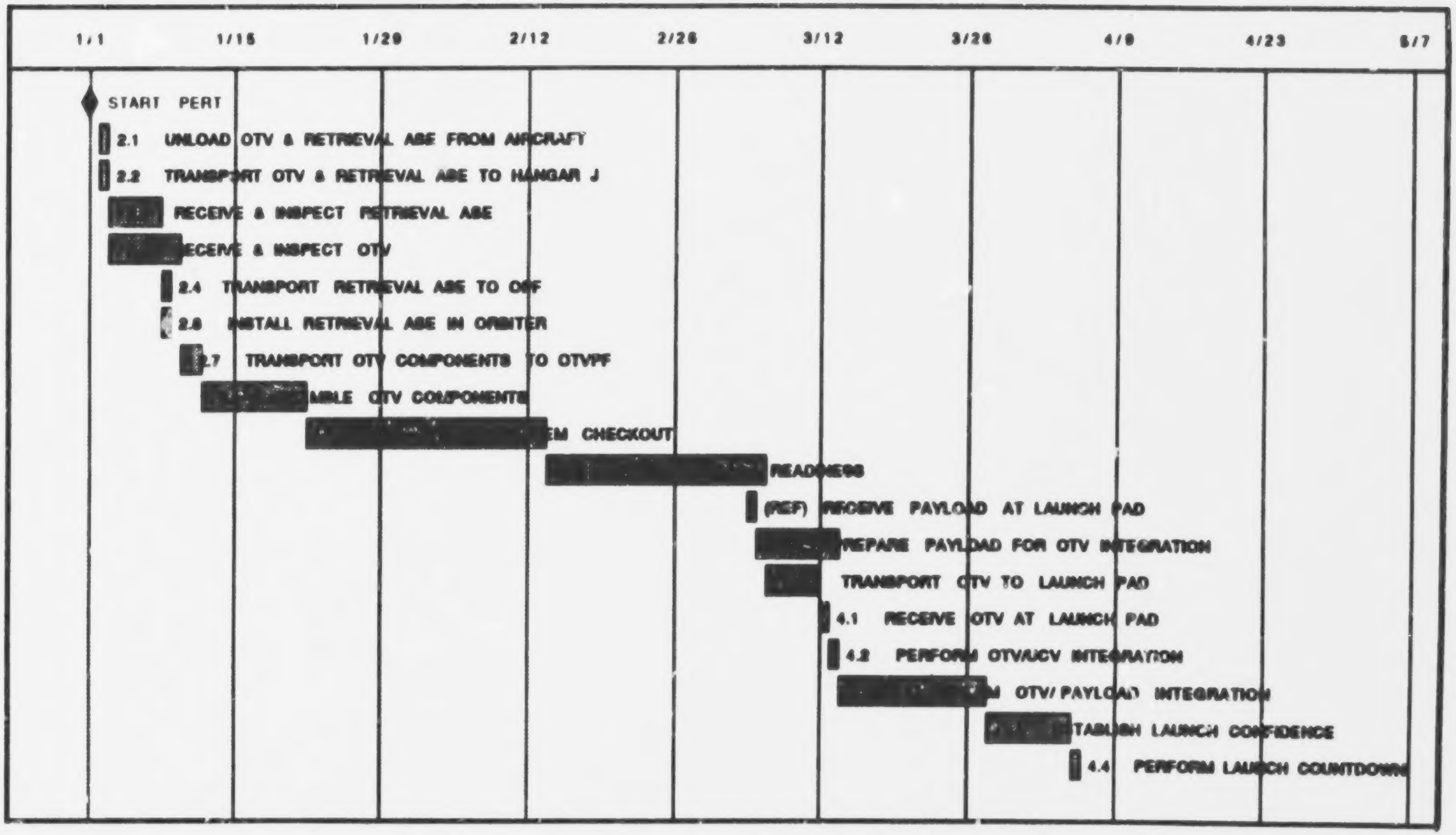

Figure 3-17. UCV GBOTV Initial Timeline: Shuttle/Centaur Type Facility Shuttle Centaur Automation

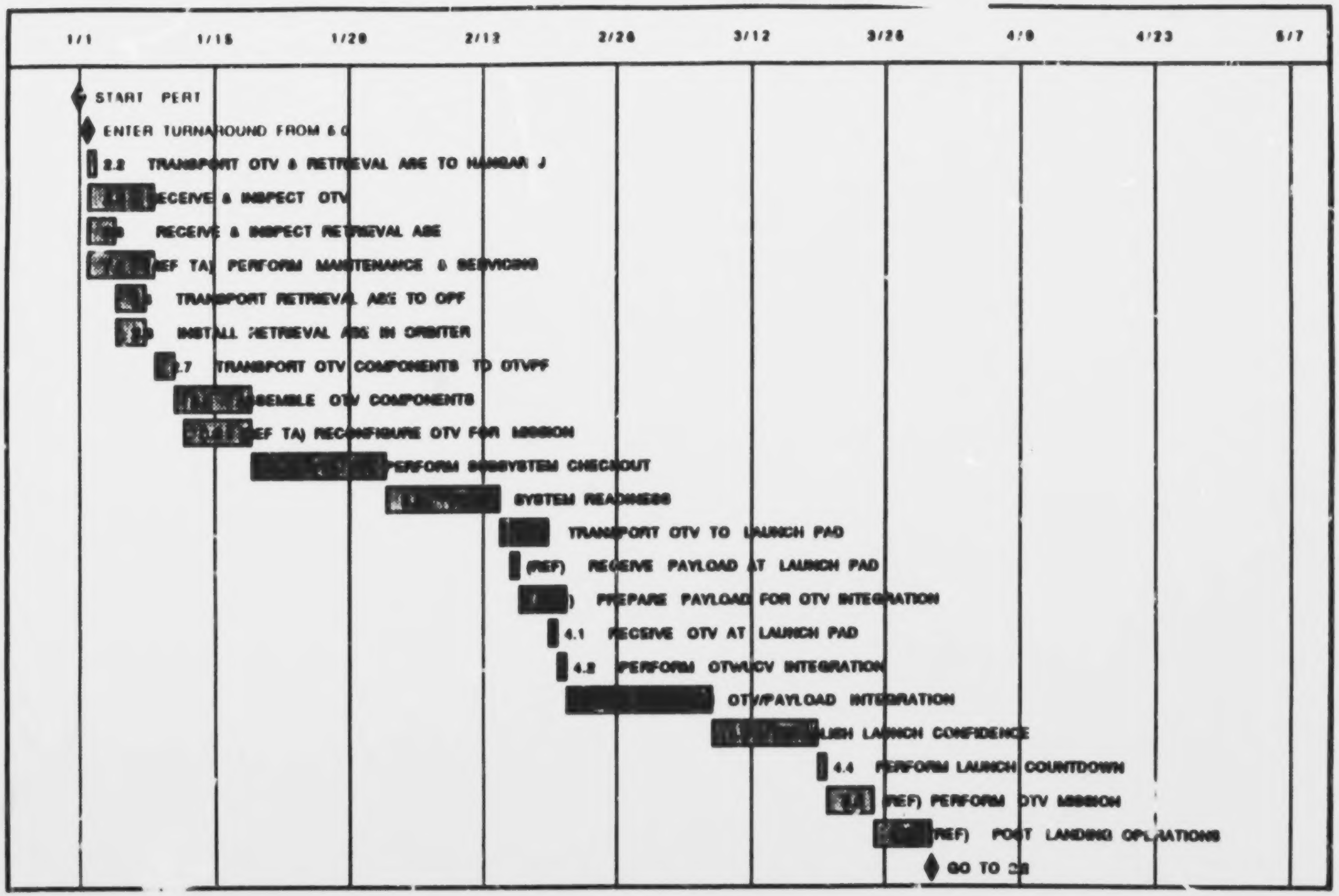

Figure 3-18. UCV GBOTV Turnaround Timeline: Shuttle/Centaur Type Facility, Shuttle Centaur Automation

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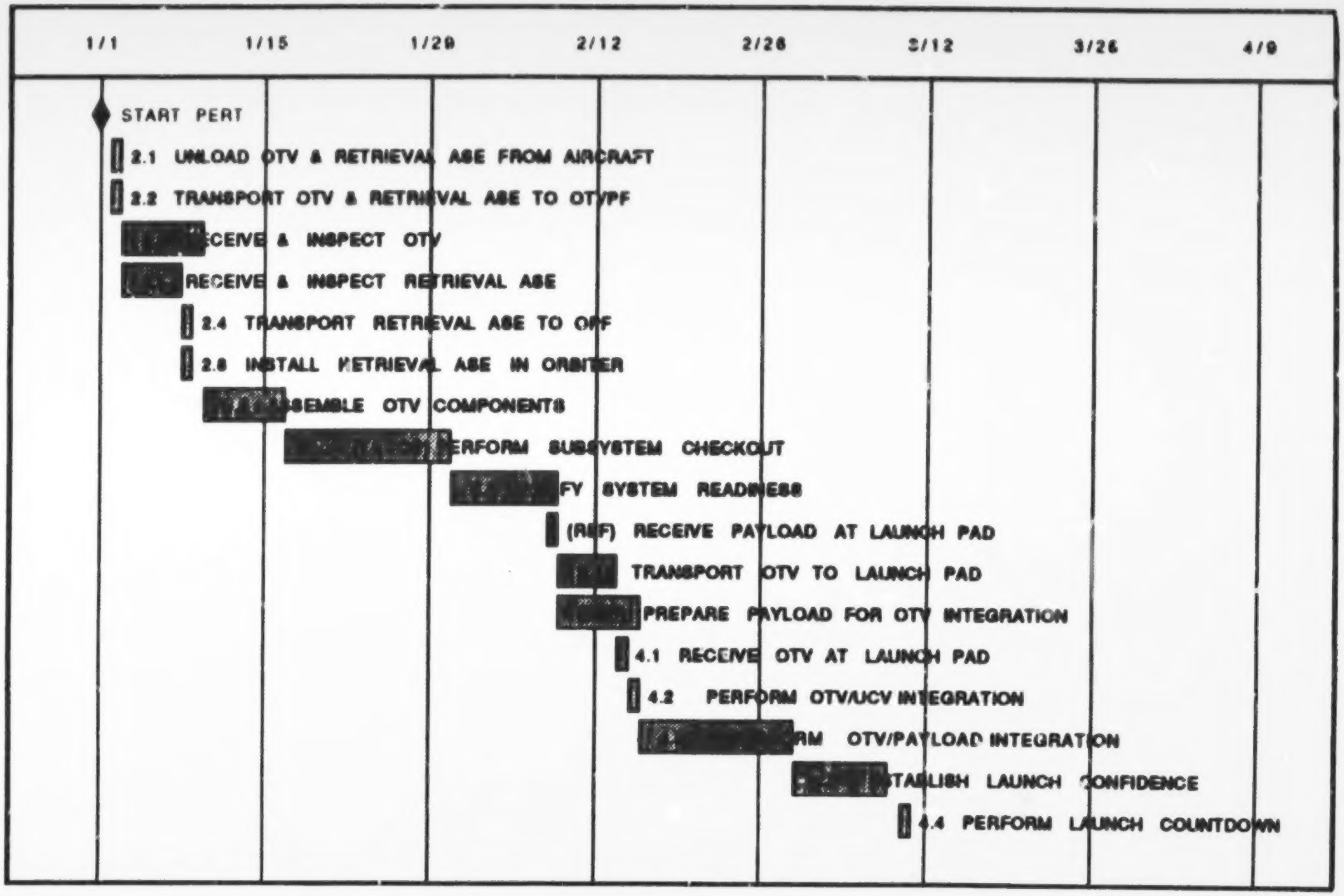

Figure 3-19. UCV GBOTV Initial Timeline: IPF, Full Automation

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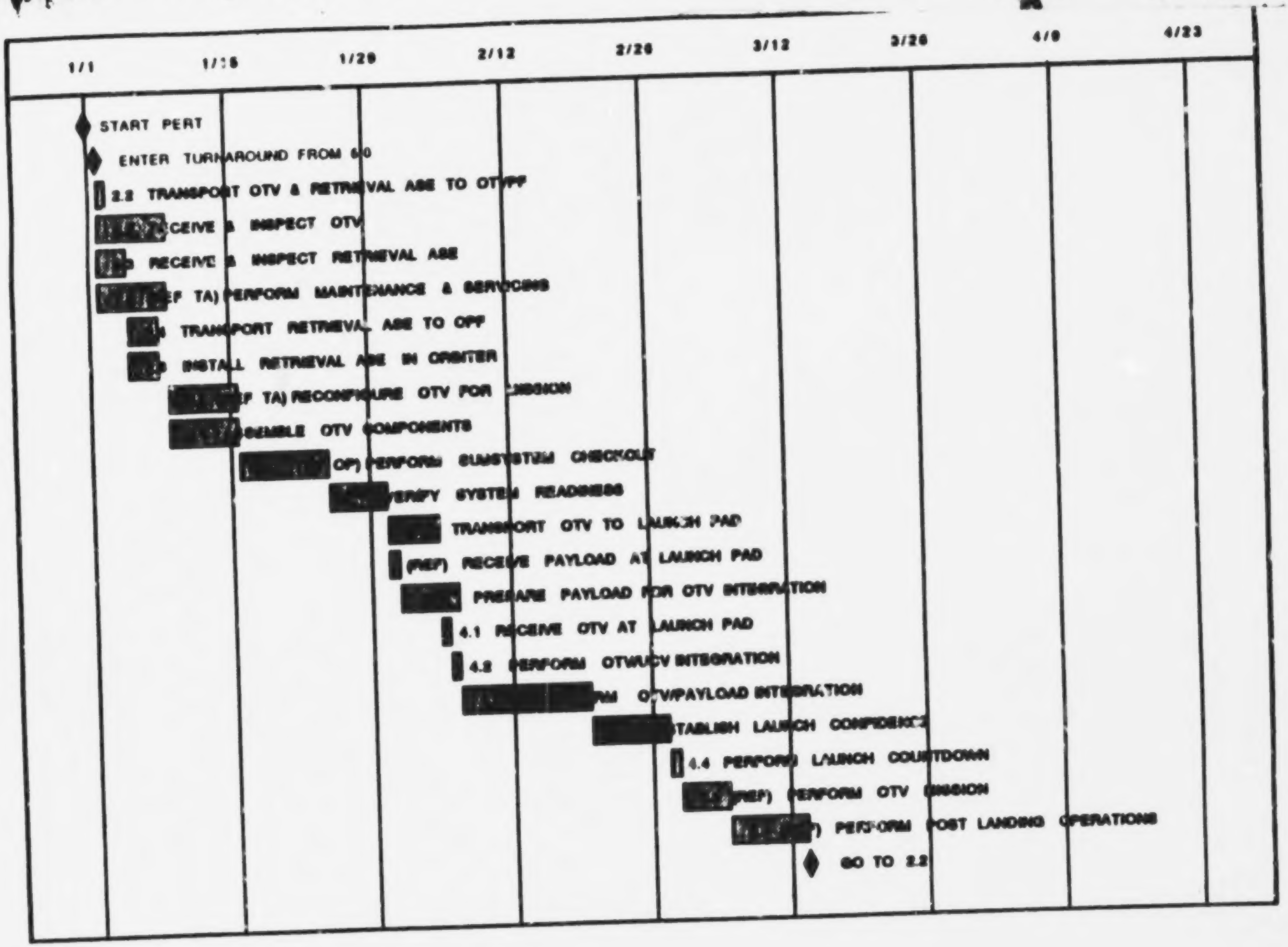

Figure 3-20. UCV GBOTV Turnaround Timeline: IPF, Full Automation

3.5.6 **RECOMMENDATIONS**. The following is the recommended approach for the UCV OTV ground process:

a. IPF
   1. Reduces transportation and retesting.
   2. Accommodates vehicle more efficiently.
   3. Reduces manhours.

b. Automated checkout
   1. Reduces manhours.
   2. Reduces potential for manual errors.
   3. Increases safety.

c. Double-shift operation
   1. Reduced number of vehicles in process.
   2. Reduced number of processing bays.

3.5.7 **RECOMMENDED TASK DEFINITIONS**. The task description sheets (see Table 3-21 as an example) contain data peculiar to each Level 2 task of the OTV turnaround. The task identification code and descriptor are the same as those used throughout the study. The purpose and a narrative description of the task are presented along with the resource requirements, task duration and frequency. The resource requirements include the crew size and manhour requirements for the tasks in addition to the accommodations required to perform the tasks. A complete set of the task description sheets has been given to the MSFC COR Donald Saxton.

Table 3-22 summarizes the data for the five OTV concepts and the Shuttle Centaur for ground operations. The costs to process the three reusable and expendable GBOTVs are very similar. The SBOTV is much less because it only occurs 8 times on the ground compared to the others which occurs 257 times to meet the mission model.

3.6 GROUND PROCESSING SUMMARY/CONCLUSIONS

The conclusions for the ground-processing analysis that has been performed are as follows:

a. Ground processing of cargo bay GBOTVs nearly identical to Shuttle/Centaur.

b. Ground processing of UCV GBOTVs similar to Atlas/Centaur and Shuttle/Centaur.

c. Recommend IPF for GBOTVs.

d. Automated ground processing operations where possible.

e. GBOTV initial launch 6 weeks - 9200 manhours.

f. Nominal turnaround GBOTV 5 weeks + mission - 7800 manhours

g. UCV OTV initial launch 5 weeks - 6500 manhours.

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS			
		INITIAL PROCESSING		TURNAROUND	
		S/C FACILITY S/C AUTOMATION	INTEGRATED FAC. FULLY AUTOMATED	S/C FACILITY S/C AUTOMATION	INTEGRATED FAC. FULLY AUTOMATED
2.1	UNLOAD OTV & ASE FROM AIRCRAFT	72	72	–	–
2.2	TRANSPORT OTV & ASE TO HANGAR J/IPF	22	22	22	22
2.3	RECEIVE AND INSPECT ASE	72	72	72	72
2.4	TRANSPORT ASE TO OPF	44	44	44	44
2.8	INSTALL ASE IN ORBITER	48	48	48	48
2.5	RECEIVE AND INSPECT OTV	512	512	512	512
2.7	TRANSPORT OTV TO OTVPF	108	–	108	–
3.1	MATE OTV CORE TO FACILITY	96	96	96	96
3.3	ASSEMBLE OTV	316	268	316	268
3.4	PERFORM SUBSYSTEM CHECKOUT	3268	1282	1980	892
3.5	VERIFY SYSTEM READINESS	2273	1146	1060	642
3.12	TRANSPORT OTV TO LAUNCH PAD	376	376	376	376
4.1	RECEIVE OTV LAUNCH PAD	200	160	200	160
4.2	PERFORM UCV/OTV INTEGRATION	168	168	168	168

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Table 3-17. UCV GBOTV Manhour Requirements

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS			
		INITIAL PROCESSING		TURNAROUND	
		S/C FACILITY S/C AUTOMATION	INTEGRATED FAC. FULLY AUTOMATED	S/C FACILITY S/C AUTOMATION	INTEGRATED FAC. FULLY AUTOMATED
4.5	PERFORM OTV AND PAYLOAD INTEGRATION	1284	1064	1284	1064
4.3	ESTABLISH LAUNCH CONFIDENCE	1296	968	1296	968
4.4	PERFORM LAUNCH COUNTDOWN	648	360	648	360
5.0	PERFORM OTV MISSION	–	–	–	–
6.0	PERFORM POST MISSION OPS	–	–	384	384
7.0	PERFORM MAINTENANCE & SERVICING	–	–	(40)	(40)
8.0	RECONFIGURE OTV FOR MISSION	–	–	(80)	(80)
	TOTAL MANHOURS	10686	6546	8518	5980

( ) OPTIONAL TASKS NOT INCLUDED IN TOTAL

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Table 3-17. UCV GBOTV Manhour Requirements, Contd

OPTION / RESOURCE COMMITTMENT	S/C FACILITY WITH S/C AUTOMATION	INTEGRATED FULLY AUTOMATED
INITIAL PROCESSING (MANHOURS)	10686	6546
TURNAROUND (MANHOURS)		
MIN	8518	5980
MAX	11118	6962
NOMINAL	8886	6186
AVERAGE CREW REQ/SHIFT	25	20
PEAK CREW REQ BY DISCIPLINE PER SHIFT	95	85
ELAPSED TIME (SHIFTS)	68	51
5-DAY WORK WEEK DOUBLE SHIFTS (WEEKS)	6.8	5.1

Table 3-18. UCV GBOTV Manpower Summary

CRITERIA / OPTION		S/C FACILITY WITH S/C AUTOMATION	INTEGRATED FULLY AUTOMATED
PROCESSING MANHOURS	INITIAL	10,686	6,546
	NOMINAL TURNAROUND	8,886	6,186
VEHICLES/BAYS TO MEET MISSION LAUNCH SCHEDULE*		1994 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES	1994 - 1 BAY 1996 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES
TOTAL MANHOURS x 10^6		2.3	1.6
MANHOUR COST ($M)		99	69
FACILITY COST ($M)		27	28
SUPPORT EQUIPMENT COST ($M)		27	37
COST ($M)**		153	134

✓ RECOMMENDED

* DOES NOT CONSIDER MULTIPLE STAGES

** DIRECT VEHICLE OPERATIONS COSTS 257 MISSIONS

Table 3-19. UCV GBOTV Operations Trade Study

OTV TASK NO.	TASK DESCRIPTION (CARGO BAY OTV)	MANHOUR REQUIREMENTS		OTV TASK NO.	TASK DESCRIPTION (UCV OTV)	MANHOUR REQUIREMENTS	
		INITIAL PROCESSING	TURN-AROUND			INITIAL PROCESSING	TURN-AROUND
2.1	UNLOAD OTV FROM AIRCRAFT	72	–	2.1	UNLOAD OTV & ASE FROM AIRCRAFT	72	–
2.2	TRANSPORT OTV TO HANGAR J/IPF	22	22	2.2	TRANSPORT OTV & ASE TO HANGAR J/IPF	22	22
2.3	RECEIVE AND INSPECT ASE	280	280	2.3	RECEIVE AND INSPECT ASE	72	72
2.4	TRANSPORT ASE TO OTVPF	–	–	2.4	TRANSPORT ASE TO OPF	44	44
2.5	OTV RECEIVE AND INSPECT	488	488	2.8	INSTALL ASE IN ORBITER	48	48
2.6	ASSEMBLE OTV AND INSTALL BALLUTE	208	208	2.5	RECEIVE AND INSPECT OTV	512	512
2.7	TRANSPORT OTV TO OTVPF	–	–	2.7	TRANSPORT OTV TO OTVPF	–	–
3.1	MATE ASE TO FACILITY	48	48	3.1	MATE OTV CORE TO FACILITY	96	96
3.2	PERFORM ASE SUBSYSTEM CHECKOUT	786	456	3.3	ASSEMBLE OTV	268	268
3.3	MATE OTV TO ASE	1040	840	3.4	PERFORM SUBSYSTEM CHECKOUT	1282	862
3.4	PERFORM SUBSYSTEM CHECKOUT	1764	1376	3.5	VERIFY SYSTEM READINESS	1148	042
3.5	VERIFY SUBSYSTEM READINESS	1772	720	3.12	TRANSPORT OTV TO LAUNCH PAD	376	376
3.6	TRANSPORT OTV TO VPF	–	–				
3.7	RECEIVE OTV AT VPF	–	–				

[illegible]

Table 3-20. Ground Processing Manhour Requirements Comparison: Cargo Bay Versus UCV OTV

OTV TASK NO.	TASK DESCRIPTION (CARGO BAY OTV)	MANHOUR REQUIREMENTS		OTV TASK NO.	TASK DESCRIPTION (UVC OTV)	MANHOUR REQUIREMENTS	
		INITIAL PROCESSING	TURN-AROUND			INITIAL PROCESSING	TURN-AROUND
3.8	PREPARE OTV FOR SPACECRAFT MATING	80	–				
3.9	MATE OTV AND SPACECRAFT	102	104				
3.10	PERFORM OTV AND SPACECRAFT CHECKOUT	154	154				
3.11	VERIFY ORBITER INTERFACE	96	96				
3.12	TRANSPORT PAYLOAD TO CX39	418	418	4.1	RECEIVE OTV LAUNCH PAD	160	160
4.1	RECEIVE PAYLOAD AT CX39	176	176	4.2	PERFORM UCV/OTV INTEGRATION	168	168
4.2	PERFORM ORBITER/PAYLOAD INTEGRATION	708	708	4.5	PERFORM OTV AND PAYLOAD INTEGRATION	1064	1064
4.3	ESTABLISH LAUNCH CONFIDENCE	624	624	4.3	ESTABLISH LAUNCH CONFIDENCE	968	968
4.4	PERFORM LAUNCH COUNTDOWN	360	360	4.4	PERFORM LAUNCH COUNTDOWN	360	360
5.0	PERFORM OTV MISSION	–	–	5.0	PERFORM OTV MISSION	–	–
6.0	PERFORM POST MISSION OPS	–	384	6.0	PERFORM POST MISSION OPS	–	384
7.0	PERFORM MAINTENANCE & SERVICING	–	(40)	7.0	PERFORM MAINTENANCE & SERVICING	–	(40)
8.0	RECONFIGURE OTV FOR MISSION	–	(80)	8.0	RECONFIGURE OTV FOR MISSION	–	(80)
	TOTAL MANHOURS	9202	7462		TOTAL MANHOURS	6548	5990

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( ) OPTIONAL TASKS NOT INCLUDED IN TOTAL

MANHOUR DIFFERENCE IS MAINLY IN INTEGRATION AND CHECKOUT OF ASE FOR CARGO BAY AND NO CRYOGENIC TERMINAL COUNT DOWN ON UCV UNTIL ON PAD CONFIDENCE TEST.

Table 3-20. Ground Processing Manhour Requirements Comparison: Cargo Bay Versus UCV OTV

h. UCV OTV nominal turnaround 5 weeks + mission - 6200 manhours.

i. Ground processing of SBOTV relatively simple
   1. Simple ASE.
   2. No Orbiter cryo integration.
   3. No payload integration.

j. Recommend shared ground processing facility for SBOTV.

TASK-IDENT	DESCRIPTOR
4.2	PERFORM OTV/UCV INTEGRATION

PURPOSE

INSTALL OTV ON UCV.

TASK DESCRIPTION

INSTALL OTV ON UCV. CONNECT OTV TO PAD ELECTRICAL AND FLUID INTERFACES AND VERIFY THOSE INTERFACES.

TASK DURATION	TASK FREQUENCY
8 HOURS (1 DAYS)	EACH FLIGHT

RESOURCE REQUIREMENTS

CREW

	CREW SIZE	MANHOURS
ENGINEERS	6	44
MECHANICS	6	40
TECHNICIANS	5	40
INSPECTORS	6	44
POWER CREW		
TOTAL	23	168

ACCOMMODATIONS

UCV LAUNCH COMPLEX
UCV
CONTROL ROOM
CCLS

SPARES

OTHER VEHICLE SYSTEMS AFFECTED

Table 3-21. Task Description Sheet: Initial Ground Processing - UCV - IPF

GROUND OPERATIONS SUMMARY - SELECTED APPROACHES

	S/C	EXPENDABLE GBOTV	REUSABLE CARGO BAY GBOTV	REUSABLE ACC GBOTV	REUSABLE SBOTV	REUSABLE UCV GBOTV
INITIAL C/0 - MHRS	33,000	9,138	9,202	9,278	10,332	6,546
TURNAROUND - MHRS						
(MIN)	–	–	7,462	7,514	–	5,980
(NOMINAL)	–	–	7,820	7,763	–	6,186
FACILITY TASKS	S/C FACILITY/ TASKS	INTEGRATED FACILITY/ FULLY AUTOMATED TASKS	INTEGRATED FACILITY/ FULLY AUTOMATED TASKS	INTEGRATED FACILITY/ FULLY AUTOMATED TASKS	S/C FACILITIES/ FULLY AUTOMATED TASKS	INTEGRATED FACILITY/ FULLY AUTOMATED TASKS
VEHICLES/BAYS TO MEET LAUNCH SCHEDULE	1 BAY	1996 - 2 BAYS 2006 - 3 BAYS 257 VEHICLES	1996 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES	1996 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES	1 BAY 8 VEHICLES	1996 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES
TOTAL MHRS X 10^3 (2 SHIFTS)	–	2,348	2,026	2,006	72*	1,592
MANHOURS COST ($M)	–	101	87	86	3	69
FACILITY COST ($M)	–	28	28	28	2	28
SUPPORT EQUIPMENT COST ($M)	–	37	37	37	37	37
COST ($M)**	–	166	152	151	42	134

*SINGLE SHIFT
**DIRECT VEHICLE OPERATIONS COSTS
257 MISSIONS

9/29/87

SECTION 4
SPACE OPERATIONS ANALYSIS/TRADE STUDIES/RECOMMENDED TASKS

This section covers the operations of an SBOTV at the Space Station. First, the requirements for space processing will be presented including the ones for the tasks and the maintenance facility and support equipment. In addition, the space operation hazard analysis will be discussed which imposes requirements on both the operations and the design of the SBOTV and the maintenance accommodations at the Space Station. The functional flow of the space-based tasks will be identified. The operations trade studies will then be discussed including proximity operations, payload integration, launch, and servicing maintenance. Manpower requirements for the three alternative methods of accomplishing the turnaround operations will be presented in the trade study comparison charts along with attendent design, operations, and cost factors. The recommended space operations approaches with the timelines and manpower will be identified along with the selection rationale.

A comparison of ground-based and space-based processing tasks and equivalent manhours will be presented to help understand where the true differences lie. Next, the definition of the recommended space operation tasks will be presented along with the identification of the required accommodations support equipment. The support equipment maintenance requirements will be discussed.

Finally, conclusions from the space operations analysis will be presented which essentially say that an SBOTV can be based at the Space Station and turned around in a safe and cost-effective manner.

4.1 SBOTV PROCESSING REQUIREMENTS.

In the first part of the study, the turnaround task requirements were generated (see Table 4-1). Shown are the task requirements and a reference to the Shuttle Centaur ground-processing tasks were applicable for traceability. Included is the requirements for the initial delivery of the OTV and for the turnaround operations. From the OTV definition studies, the assumption is made that the SBOTV is good for 40 missions before being replaced

4.2 SBOTV MAINTENANCE FACILITY/SUPPORT EQUIPMENT

The major elements to maintain/service the OTV at the Space Station include the maintenance, propellant storage, control station and maintenance area (pressurized module), and storage facility, hangar, tools, spares storage. The element requirements are as follows:

a. Maintenance and storage facility
   1. Main truss support structure.
   2. OTV internal hangar berthing fixture (rotary).
   3. Electrical interconnects between internal berthing interface, OTV control equipment and power source.
   4. OTV external berthing fixture.

REQUIREMENTS	SHUTTLE CENTAUR TASKS(REF)
1.0 DELIVER OTV SYSTEM TO LAUNCH SITE	
2.0 PERFORM LAUNCH SITE PROCESSING	
3.0 TRANSFER OTV TO SPACE STATION	
3.1 LAUNCH STS	
3.2 RENDEZVOUS ORBITER TO STATION PROXIMITY	
3.3 OPEN CARGO BAY DOORS	
3.4 MANEUVER ORBITER TO STATION	
3.5 DOCK ORBITER TO STATION	
4.0 PERFORM INITIAL DELIVERY AND ASSEMBLY	
4.1 OFF-LOAD OTV FROM ORBITER	
4.2 ASSEMBLE OTV COMPONENTS	(1.1, 1.4.2 & 3.5.1)
4.2.1 ATTACH OTV COMPONENTS	
4.2.2 ASSEMBLE AEROBRAKE COMPONENTS	
4.2.3 DEPLOY AND ATTACH AEROBRAKE TO OTV	
4.3 PERFORM INITIAL OTV TESTING	
4.3.1 CHECKOUT ELECTRICAL SYSTEM	
4.3.1.1 ACTIVATE ELECTRICAL SYSTEM	
4.3.1.2 POWER GENERATION SYSTEM	(3.5.3)
4.3.1.3 AVIONIC SUBSYSTEMS	(2.4.38)
4.3.1.4 ENGINE	(2.4.3, 2.4.40 & 2.9)
4.3.1.5 RF SYSTEM	(2.4.54)
4.3.1.6 TELEMETRY SYSTEM	(2.4.27)
4.3.1.7 OTV TO CONTROL STATIONS	(2.4.31 & 2.4.33)
4.3.2 CHECKOUT AEROBRAKE SYSTEM	(4.3.2)
4.3.3 CHECKOUT PRESSURE SYSTEM	
4.3.3.1 PNEUMATIC SYSTEM PREPS	(1.4.7)
4.3.3.2 PNEUMATIC SYSTEM FUNCTIONAL OPERATION	(2.4.6 & 1.4.9)
4.3.4 CHECKOUT RCS SYSTEM	
4.3.4.1 RCS PRESSURE	
4.3.4.2 RCS SYSTEM LEAK & FUNCTIONAL	(1.4.1)
4.3.5 CHECKOUT PROPULSION/FLUID SYSTEM	(2.4.12)
4.3.5.1 SYSTEM READINESS	(2.5)
4.3.5.2 LEAK CHECKS	(2.4.17, 2.8.1, 2.8.4 & 2.9)
4.3.6 PERFORM TERMINAL COUNTDOWN DEMONSTRATION	(2.4.10, 2.4.19, & 2.4.47)
5.0 PREPARE FOR MISSION (TURNAROUND ENTRY POINT)	(2.5)
5.1 CONFIGURE OTV FOR MISSION	
5.1.1 PAYLOAD DEPENDENT KITS	
5.1.2 ADDITIONAL TANKS OR STAGES	
5.1.3 SOFTWARE	
5.2 MATE OTV AND PAYLOAD	
5.2.1 TRANSFER OTV TO EXTERNAL BERTHING FIXTURE(EBF)	(3.2)
5.2.2 BERTH OTV AT EBF	(2.2.14 & 2.12))
5.2.3 VERIFY OTV SYSTEM OPERATIONAL	(2.2.16, 2.3, 2.4.34, 3.1, 3.1.1, 3.2.2 & 3.5.1) (3.5.3)
5.2.4 TRANSLATE PAYLOAD TO OTV	
5.2.5 MATE OTV & PAYLOAD	
5.3 PERFORM PRELAUNCH CHECKS	(3.4 & 3.5)
5.3.1 POWER GENERATION SYSTEM	
5.3.2 AVIONIC SYSTEM	(2.4.38)
5.3.3 RF SYSTEM	(2.4.3 & 2.4.40)
5.3.4 TELEMETRY SYSTEM	(2.4.47)
5.3.5 OTV TO CONTROL STATIONS	(2.4.31 & 2.4.33)
5.4 TRANSFER PROPELLANTS TO OTV	(4.3.2)
5.4.1 CHILLDOWN OTV SYSTEM	
5.4.2 PERFORM LEAK CHECKS	
5.4.3 TRANSFER PROPELLANTS	(2.4.10)

Table 4-1. SBOTV Turnaround Operations

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REQUIREMENTS	SHUTTLE CENTAUR TASKS(REF)
6.0 DEPLOY ON MISSION	
6.1 SEPARATE OTV/PL FROM STATION	(4.9)
6.2 MANEUVER OTV/PL TO IGNITION COORDINATES	
6.3 INITIATE FLIGHT OPERATIONS	
7.0 PERFORM MISSION	
8.0 RETURN TO STATION	
8.1 RENDEZVOUS OTV TO STATION PROXIMITY	
8.2 ASSURE OTV IS SAFE FOR STATION APPROACH	
8.3 MANEUVER OTV TO STATION	(1.4.9)
8.4 CAPTURE OTV	
8.5 BERTH OTV	
9.0 PERFORM MAINTENANCE AND SERVICING	(2.2.16, 2.4.34, 2.3, 3.1, 3.1.1 & 3.2.2)
9.1 TRANSFER RESIDUAL PROPELLANTS TO STATION	
9.1.1 ENGAGE FLUID AND ELECTRICAL LINES	
9.1.2 PERFORM LEAK CHECK	(2.2.10)
9.1.3 CHILLDOWN TRANSFER LINES	(2.4.10)
9.1.4 TRANSFER PROPELLANTS FROM OTV TO STATION	
9.1.5 PURGE AND SAFE PROPELLANT DEPOT	
9.1.6 DISENGAGE FLUID AND ELECTRICAL INTERFACE	
9.2 SECURE OTV IN HANGAR	
9.2.1 RELEASE OTV FROM EBF	
9.2.2 TRANSLATE OTV INTO HANGAR	
9.2.3 POSITION OTV AT HANGAR BERTHING FIXTURE	(2.12)
9.2.4 ENGAGE HANGAR BERTHING MECHANISM AND LATCH	(3.2.2 & 3.5.1)
9.2.5 RELEASE RMS AND STOM	(3.2.2 & 3.5.1)
9.3 ASSESS OTV OPERATIONAL STATUS	
9.3.1 PERFORM VISUAL INSPECTION OF OTV	
9.3.2 PERFORM FLIGHT DATA ANALYSIS (IF NO FAULT PROCEED WITH 9.4)	(2.8.5)
9.3.3 VERIFY ELECTRICAL FAILURE AND FAULT ISOLATE	
9.4 PLAN OTV MAINTENANCE ACTIVITIES	
9.4.1 SCHEDULED MAINTENANCE	
9.4.1.1 NORMAL SERVICING	
9.4.1.2 PREVENTIVE MAINTENANCE	
9.4.2 UNSCHEDULED MAINTENANCE	
9.5 PERFORM OTV MAINTENANCE	
9.5.1 PERFORM NORMAL SERVICING	
9.5.1.1 REMOVE WATER FROM FUEL CELL	
9.5.1.2 REPLENISH RCS PROPELLANT	
9.5.2 PERFORM PREVENTIVE MAINTENANCE	(2.4.12 & 2.6.2)
9.5.2.1 REMOVE AND REPLACE ENGINES	
9.5.2.2 REMOVE AND REPLACE AEROBRAKE TPS	(2.4.19 & 2.4.54)
9.5.3 PERFORM UNSCHEDULED MAINTENANCE	
9.5.3.1 REMOVE AND REPLACE AVIONICS	
9.5.3.2 REMOVE AND REPLACE FUEL CELL	(2.4.3 & 2.4.40))
9.5.3.3 REMOVE AND REPLACE ENGINE	(2.4.39)
9.5.3.4 REMOVE AND REPLACE AEROBRAKE TPS	(2.4.19 & 2.4.54)
9.5.3.5 REMOVE AND REPLACE AEROBRAKE	
9.5.3.6 REMOVE AND REPLACE RCS SYSTEM	
9.5.4 PERFORM SYSTEMS OPERATIONAL TEST	(1.4.9, 2.4.3, 2.4.27, 2.4.31, 2.4.33, 2.4.38, 2.4.10, 2.4.54 & 3.5.3)
9.6 PLACE OTV IN STORAGE CONDITION	
9.7 REMOVE OTV FROM STORAGE (GO TO 5.0 PREPARE FOR MISSION)	

Table 4-1. SBOTV Turnaround Operations, Contd

5. Fluid lines from external berthing quick disconnect panel to propellant storage/transfer control interface.
6. Support structures for hangar and equipment.
7. TV, communications, and propellant leak detection installation.
8. RMS installation including rails, local TV, lights, and tool adapter.
9. Electrical interconnects from RMS to facility control equipment.
10. Tools and spares storage provisions.
11. EVA foot constraints/handholds/control panel.

b. Hangar

1. Hangar protective cover support structure.
2. Protective covering (Micrometeoroid and space debris).
3. Lighting and TV installation.
4. Lightweight screen for hangar opening.
5. Possible antenna installations.

c. Tools

1. EVA/RMS maintenance tools.
2. RMS astronaut work station.

d. Spares storage

1. Holding fixtures for tank.
2. Holding fixtures for avionics ORUs, ACS module, engines and aerobrake.
3. Holding fixtures for EVA/RMS maintenance tools.
4. Holding fixtures for OTV payload and manned GEO crew module.

e. Propellant storage

1. Main support structure.
2. Hydrogen storage tank.
3. Oxygen storage tank.
4. Propellant acquisition, conditioning, and gauging.
5. Fluid lines from tanks to control interface.
6. Refrigeration unit and plumbing or boil-off module.
7. Electrical interface between control unit, refrigeration unit, or boil-off and power.
8. Protective covering (micrometeoroid and space debris)
9. Heat rejection.

f. Control station and maintenance area (pressurized module)

1. Rendezvous, docking, and berthing control.
2. OTV direct control through berthing fixtures.
3. Hangar equipment control.

4. Propellant facility control.
5. Airlock for EVA operations
6. Communications and data links
7. Tools, maintenance, checkout equipment, and maintenance area.

From the above requirements, GDSS has synthesized a maintenance and servicing facility with support equipment as a baseline to conduct the space operations analysis and trade studies. Figure 4-1 shows a potential concept of an SBOTV and its hangar at the bottom of the Space Station.

Figure 4-2 shows a layout of the OTV accommodations. The hangar is located at the bottom of the dual-keel Space Station with the bottom open. This location was chosen as the best for operational factors.

The hangar is configured for storage and maintenance of up to two OTVs, OTV outrigger tanks, an OMV, and OTV payload.

Two mobile remote manipulator systems (MRMS) are required to service the vehicles. The MRMs operate on the same or opposite sides of the hangar. Tools and spare parts are brought to the MRMs on a mobile storage rack to eliminate excessive MRMS movement.

The vehicle berthing interfaces in the hangar are rotary berthing rings, which hold the vehicles at the payload interfaces. The rotary device orients the vehicle to aid in maintenance activities. The device incorporates interfaces for electrical power, propellant tank pressurization, control and data lines. Fluid interfaces are not required here.

The berthing interface outside of the hangar provides for payload integration and both fluid and electrical interfaces to the OTV. The fluid interconnects allow for propellant transfer to and from the OTV and eliminate the possibility of contamination of the hangar in event of a propellant leak.

4.3 SPACE OPERATIONS HAZARD ANALYSIS

GDSS performed a preliminary hazard analysis to identify potential hazards to accommodate/service/maintain an SBOTV in space. In addition, we identified recommended solutions to avoid the hazards.

Table 4-2 presents examples of some of the potential hazards which can occur when handling and storing liquid propellants (LH_2 and LO_2). For each hazard, several potential solutions to avoid the hazard are presented. This data and data on the following figures was considered in our analysis of the turnaround tasks and was also considered in the OTV and Space Station design tasks which are presented later in the report.

This table is typical of the hazards which would be encountered in maintaining the OTV and solutions to these hazards.

It lists the potential hazards and their solutions for normal EVA operation and contingency EVA operations.

MISSION CAPABILITY	
• GEO CIRCULAR	
---EXPENDABLE	31,890 LB
---REUSABLE	20,000 LB
• MAXIMUM DURATION	68 HRS
• GEO SERVICE STATION LOGISTICS	12,000 UP/2,000 DOWN
STAGE DESCRIPTION	
• DRY WEIGHT	9,070 LB
• BURNOUT WEIGHT	10,460 LB
• USABLE MAIN PROPELLANT	58,540 LB
• STAGE IGNITION WEIGHT	69,000 LB
• AIRBORNE SUPPORT EQUIPMENT	TBD
PROPULSION	
• PROPELLANT TYPE	O_2/H_2 (1 ATM)
• NO. MAIN ENGINE	2
• MIXTURE RATIO/ISP	6:1/485
• AVERAGE THRUST LEVEL	5,000 LB (PER ENG.)
• RCS PROPELLANT	N_2H_4
AVIONICS	
• TYPE	3 STRING
• POWER	FUEL CELL (PROPELLANT GRADE REACTANTS)

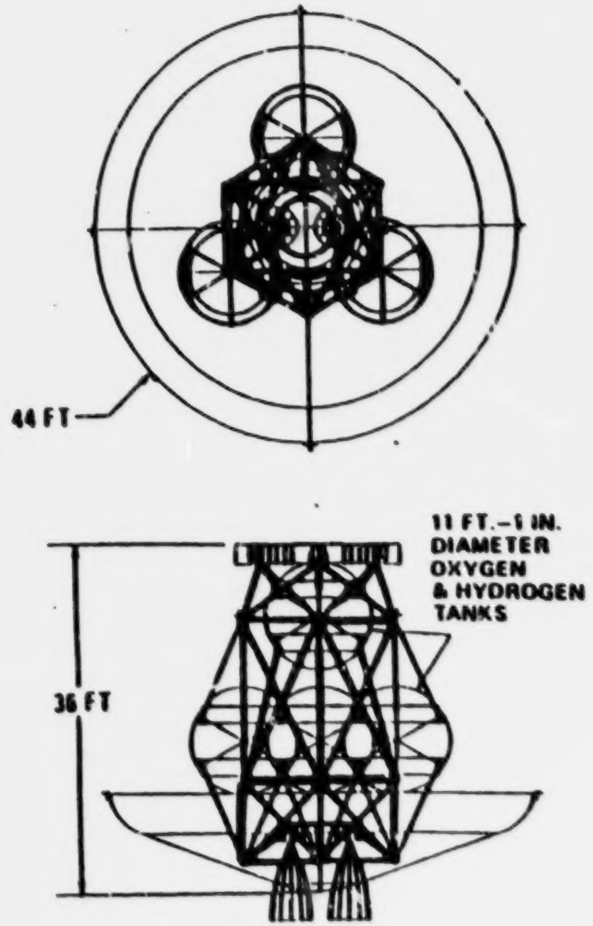

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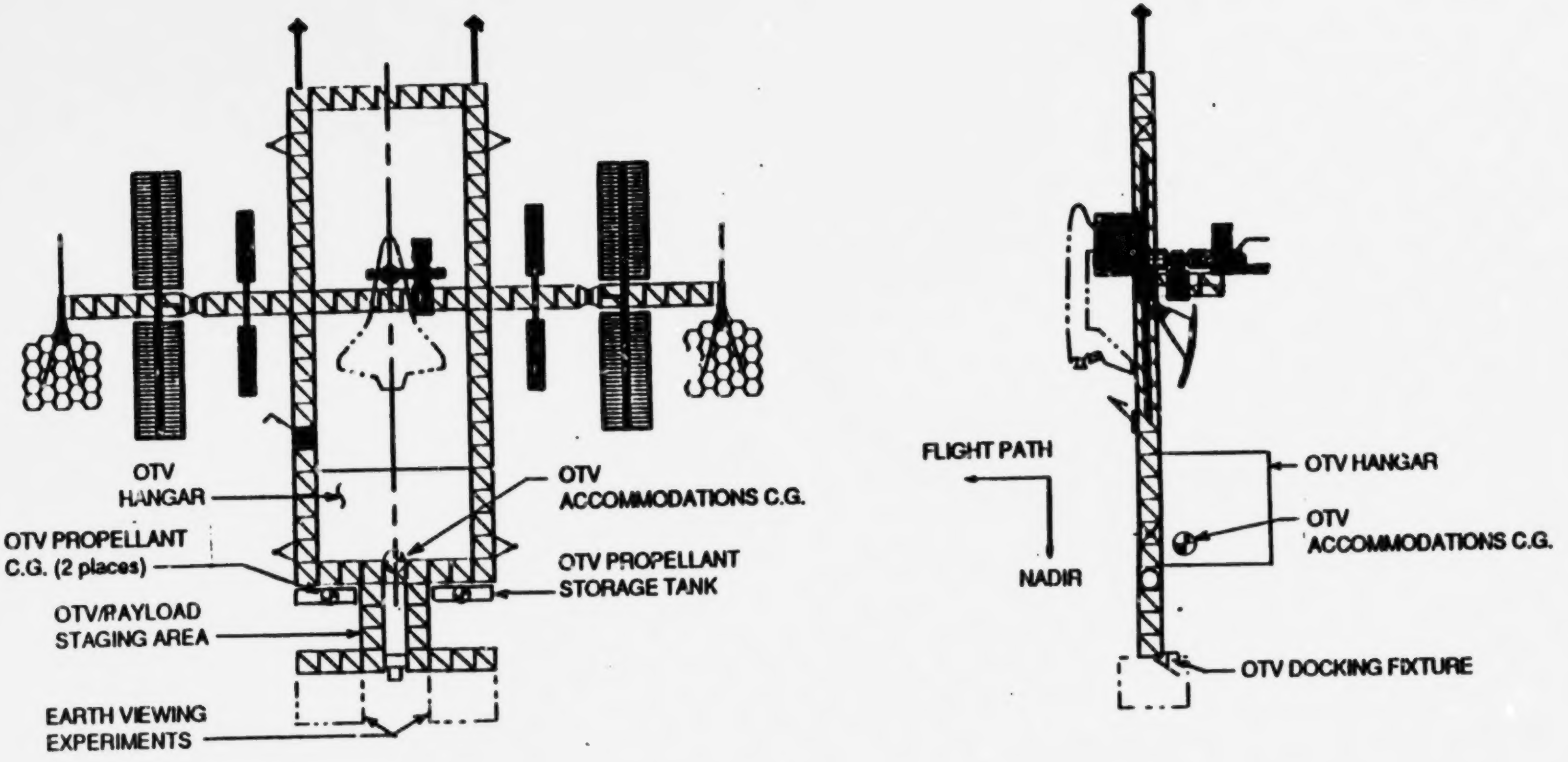
Figure 4-1. SBOTV



WEIGHT SUMMARY (lbs.)*			
OTV Accommodations	= 92000	OMV Dry	= 3000
OTV Propellants	= 200000	Payload	= 20000
OMV Propellants	= 14000		
OTV Dry	= 9070	TOTAL	= 338070

* Required to meet all NASA revision 8 missions

Figure 4-2. Space Station OTV Accommodations

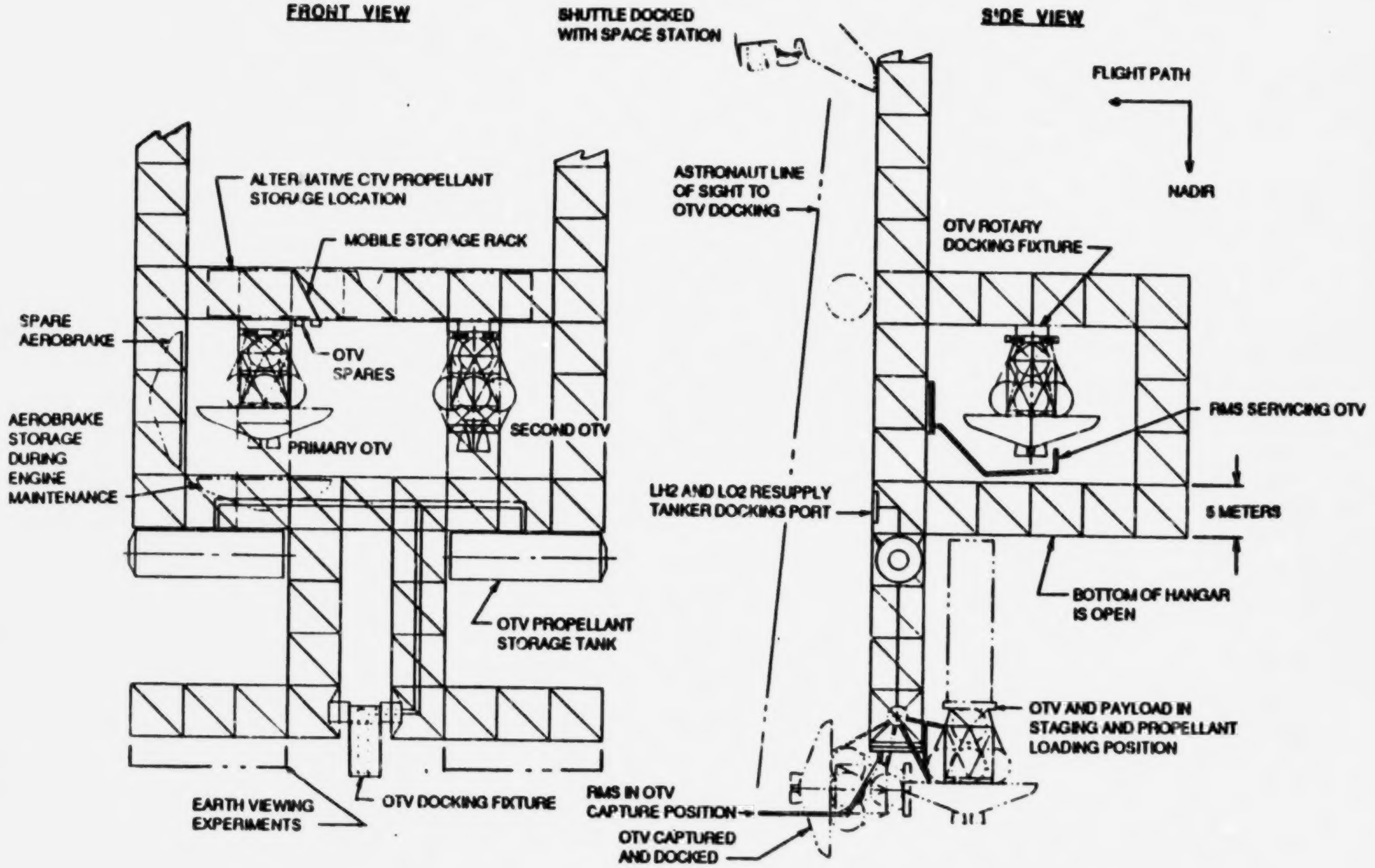

FRONT VIEW
ALTERNATIVE CTV PROPELLANT STORAGE LOCATION
MOBILE STORAGE RACK
SPARE AEROBRAKE
OTV SPARES
AEROBRAKE STORAGE DURING ENGINE MAINTENANCE
PRIMARY OTV
SECOND OTV
OTV PROPELLANT STORAGE TANK
EARTH VIEWING EXPERIMENTS
OTV DOCKING FIXTURE
SHUTTLE DOCKED WITH SPACE STATION
ASTRONAUT LINE OF SIGHT TO OTV DOCKING
LH2 AND LO2 RESUPPLY TANKER DOCKING PORT
RMS IN OTV CAPTURE POSITION
OTV CAPTURED AND DOCKED
SIDE VIEW
FLIGHT PATH
NADIR
OTV ROTARY DOCKING FIXTURE
RMS SERVICING OTV
5 METERS
BOTTOM OF HANGAR IS OPEN
OTV AND PAYLOAD IN STAGING AND PROPELLANT LOADING POSITION

Figure 4-2. Space Station OTV Accommodations

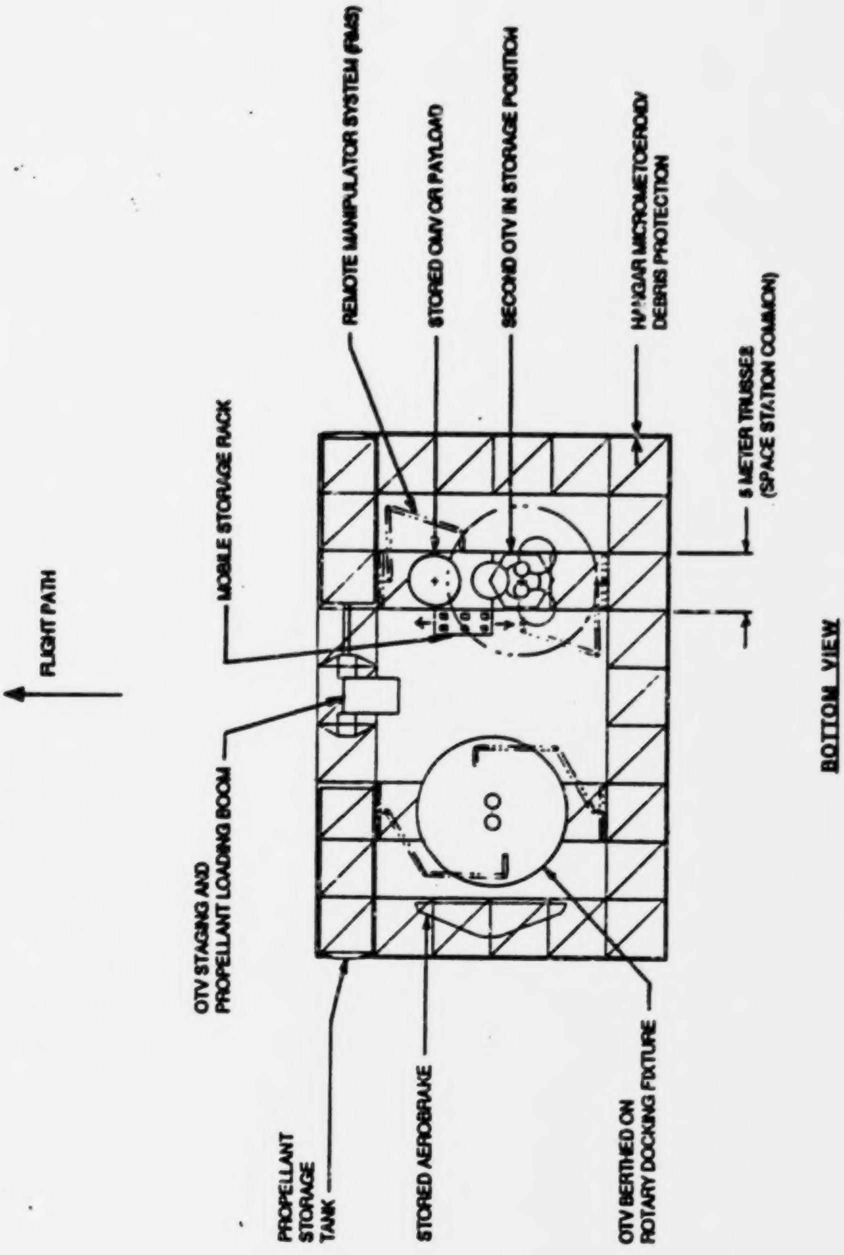

FLIGHT PATH
OTV STAGING AND PROPELLANT LOADING BOOM
MOBILE STORAGE RACK
REMOTE MANIPULATOR SYSTEM (RMS)
STORED OMV OR PAYLOAD
SECOND OTV IN STORAGE POSITION
HANGAR MICROMETEOROID/ DEBRIS PROTECTION
5 METER TRUSSES (SPACE STATION COMMON)
PROPELLANT STORAGE TANK
STORED AEROBRAKE
OTV BERTHED ON ROTARY DOCKING FIXTURE
BOTTOM VIEW

Figure 4-2. Space Station OTV Accommodations

Operational Phase: Handling and Storage of Liquid Propellants

Potential Hazard	Recommendation
Loss of mechanical properties of ferrous alloy materials in the presence of liquid hydrogen can lead to brittleness.	Metals which are compatible with low temperatures should be used, such as: stainless steel (300 and other austenitic series), copper, bronze, brass, Monel, aluminum, etc
Nonmetal materials can lose their mechanical properties and become brittle when subjected to liquid hydrogen.	Nonmetals which are compatible with low temperatures should be used, such as: polyester fiber (Dacron or equivalent), tetrafluoroethylene (TFE, Halon TFE, Teflon or equivalent), Mylar, nylon, etc.
Lubricants are generally not practical in the presence of liquid hydrogen, for they solidify and become brittle.	Vacuum grease is satisfactory as a sealant with "O"rings.
Rapid pressure release due to structural failure of liquid hydrogen/oxygen tank.	In general, vessels which contain liquids should be individually relieved. However, where two or more vessels are connected by piping without valves the group may be treated as a whole. Relief valves should be connected into the vapor space. The relief setting should be such as to protect the structural integrity of the vessel(s). The tank shall be of compatible material.
Ignition of a mixture of hydrogen and oxygen. The largest hazard from liquid hydrogen is the possibility of fire. In order for this to occur the hydrogen must mix with oxygen or air mixture, have some pressurization and have an energy source for ignition.	Liquid hydrogen tanks and oxygen tanks should be separated as far as practicable. It shall be impossible for the hydrogen to leak into any crew areas. Liquid hydrogen will not be transported aboard the STS.
Possible rupture of tanks, pipes or valves from internal pressure buildup due to clogging.	The tank system must be completely decontaminated and inerted before initial filling or use with liquid hydrogen. Insulate lines.

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Table 4-2. OTV Potential Hazard List and Solutions

Potential Hazard	Recommendation
Excessive pressure buildup within LOX systems.	LOX equipment shall be monitored remotely with acceptable LOX-clean types of pressure gauges. Gauges should be protected with blowout relief backs or plugs. The storage tanks shall be equipped with a bursting disc and a pressure relief valve in parallel, both discharging to the space environment through an adequately sized vent line to proclude overstress of the hangar structure from assymetrical reaction force. All lines and vessels in which LOX may be trapped between closed valves should have pressure-relief valves; if it is likely that the relief valve may freeze, rupture discs should also be provided. When LOX is being transferred from one container to another, the receiving vessel should be filled as slowly as possible to minimize the thermal shocks. A predetermined approved procedure shall be used when LOX is transferred. Provide insulation for exposed lines.
Rapid pressure release of a cryogen tank due to structural degradation from object impact.	Tanks should be evaluated for impact sensitivity in accordance with MSFC-SPEC-106.
Structural degradation of sotrage or transfer systems from incompatibility of materials.	The materials listed below are classified as generally satisfactory for use in transferring or storing hydrazine. However, for cetain specifications thero are exceptions. Each of these materials (or other possible sources) must be thoroughly tested before being put into service. Metals: stainless steel- types 303, 304, 321 and 347, nickel, aluminum- types 1100 and 3003.

2.363-60-2

Table 4-2. OTV Potential Hazard List and Solutions, Contd

Operational Phase: Maintenance- Aerobrake

Item No.	Potential Hazard	Recommendation
1.	Receive OTV in maintenance dock.	Refer to PHL on Space-Based OTV docking and berthing. Perform visual (TV) inspection of OTV.
2.	Transfer propellants to storage tanks.	Refer to PHL on Handling and Satorage of Liquid Propellants. Monitor fuel tanks and transfer system.
3.	Damage to OTV from meteoroids/radiation.	Provide a shelter/blanket around the hangar maintenance area.
4.	Exposure of crew to space environment and loss or damage of OTV components.	As many level I and II maintenance activities as is practical should be designed for replacement by automatic equipment. This operation may require EVA due to the complexity of the task.
5.	Damage to OTV or components from collision with maintenance structure, other OTV components or rail truss due to loss of communications, loss of visual or loss of lighting.	Verify handling concepts and aerobrake R&R tasks on the ground and at the space station. Only approved procedures shall be used and contingency plans should be practiced by the crew members.
6.	Injury or death to EVA crew member.	EVA shall be performed with two crew members. Third crew member will provide command and monitor functions in the command center.

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Table 4-2. OTV Potential Hazard List and Solutions, Contd

Operational Phase: EVA and Contingency EVA Operations		
Item No.	Potential Hazard	Recommendation
1.	Injury or death due to snaring, ripping, or tearing of crew member EVA suit during EVA aerobrake maintenance operations.	Components of the OTV and maintenance hangar must be free of sharp corners and objects. Two crew members will conduct EVA operations with the third member providing the control and monitor functions.
2.	Injury or death due to snaring, ripping, or tearing of crew member EVA suit during EVA engine maintenance operations.	Components of the OTV and maintenance hangar must be free of sharp corners and objects. Two crew members will conduct EVA operations with the third member providing the control and monitor functions.
3.	Injury or death due to snaring, ripping, or tearing of crew member EVA suit during EVA contingency ACS maintenance operations.	Components of the OTV and maintenance hangar must be free of sharp corners and objects. Two crew members will conduct contingency EVA operations with the third member providing the control and monitor functions.
4.	Injury or death due to snaring, ripping, or tearing of crew member EVA suit during EVA contingency Fuel Cell maintenance operations.	Components of the OTV and maintenance hangar must be free of sharp corners and objects. Two crew members will conduct contingency EVA operations with the third member providing the control and monitor functions.

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Table 4-2. OTV Potential Hazard List and Solutions, Contd

Operational Phase: EVA and Contingency EVA Operations

Item No.	Potential Hazard	Recommendation
5.	Injury or death due to snaring, ripping, or tearing of crew member EVA suit during EVA contingency Avionics maintenance operations.	Components of the OTV and maintenance hangar must be free of sharp corners and objects. Two crew members will conduct contingency EVA operations with the third member providing the control and monitor functions.
6.	Injury or death due to entrapment of a crew member during EVA operations or EVA contingency operations.	Two crew members will conduct EVA operations. Operational planning will include crew emergency procedures for loss of control , communications and malfunctioning equipment. When remotely controlled arms and cranes are being operated the EVA crew members will be stationed at an area which is safe from accidental contact with the systems.

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Table 4-2. OTV Potential Hazard List and Solutions, Contd

The following summarizes the hazard analysis that has been performed and indicates that the recommendations to avoid the hazards have been considered in the turnaround task analysis and will be incorporated into the work in task 5 and 6.

The preliminary hazard analysis summary did the following:

a. Identified potential hazards accommodating/servicing/maintaining an SBOTV in space.

b. Identified recommended solutions to avoid the hazards.

c. These recommendations have been considered in our definition of the turnaround operations analysis and will be incorporated into the definition of OTV design and interface requirements in Task 5 and the space station design, support and interface requirements in Task 6.

The conclusion is that an SBOTV can be safely maintained/serviced in space using mostly teleoperations and EVA as a contingency operation.

4.4 FUNCTIONAL FLOW

Figure 4-3 shows the top-level functional flow for the SBOTV. It includes the ground processing flow which has been discussed previously and the initial delivery to orbit which is included in the space operations analysis. It also includes the turnaround at the Space Station and the OTV mission. Turnaround at the Space Station is the only one of these functions we analyzed for this study.

Lower level functional flows were developed for OTV initial delivery and assembly and maintenance and servicing. These were used to generate the data for the trade studies which are discussed next.

4.5 SPACE OPERATIONS TRADE STUDIES

The section presents the operations trade studies that were performed.

Our approach in this study to the SBOTV turnaround operations analysis was as follows:

a. Previous space operations tasks used Atlas/Centaur processing as a data base

b. The study has updated the previous space operations tasks using the:

   1. Shuttle/Centaur processing requirements/operations data base.

   2. OTV ground processing requirements/operations tasks.

c. Ground processing tasks converted to space processing

   1. Deleted tasks not required (moving from one facility to another, etc.)

   2. Used backup personnel on the ground (quality assurance, troubleshooting, etc.)

   3. Etc.

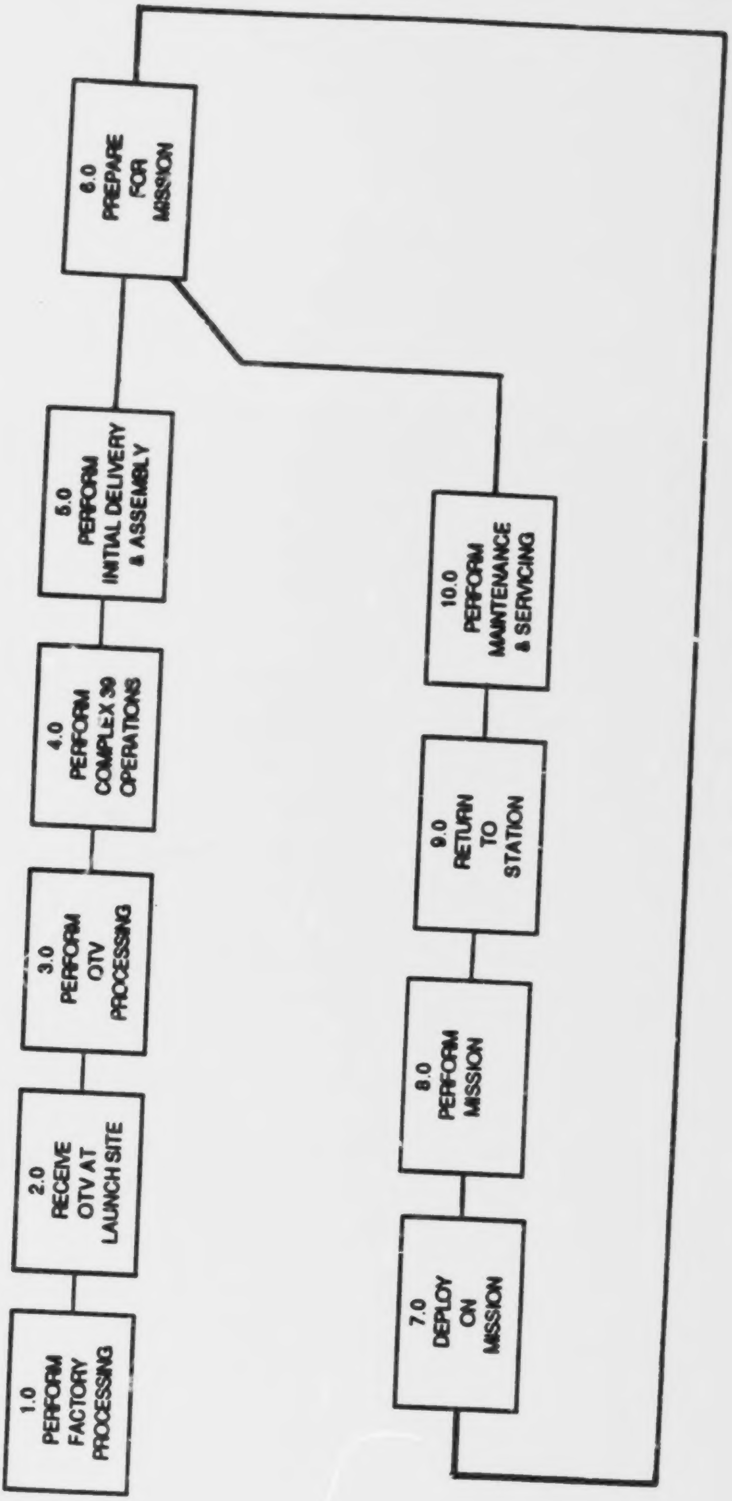
1.0 PERFORM FACTORY PROCESSING
2.0 RECEIVE OTV AT LAUNCH SITE
3.0 PERFORM OTV PROCESSING
4.0 PERFORM COMPLEX 39 OPERATIONS
5.0 PERFORM INITIAL DELIVERY & ASSEMBLY
6.0 PREPARE FOR MISSION
7.0 DEPLOY ON MISSION
8.0 PERFORM MISSION
9.0 RETURN TO STATION
10.0 PERFORM MAINTENANCE & SERVICING

Figure 4-3. SBOTV Top-Level Functional Flow

In our past studies, we used Atlas/Centaur processing as a data base. For this study we have updated our previous space operations analysis by considering the Shuttle/Centaur processing requirements/operations and the OTV ground-processing requirements/operations analysis that were presented in previous sections.

In addition, in converting ground-processing tasks to space processing we took the approach shown on the figure among other activities.

An OTV maintenance philosophy encompassing Space Station operations was developed to help us focus on the essential elements of maintenance support requirements. The maintenance philosophy is based on the three levels of maintenance as follows:

a. Three-level maintenance: Based on level-of-repair analyses
    1. Level 1: OTV local maintenance
    2. Level 2: Space Station maintenance of replaceable units
    3. Level 3: Return-to-earth maintenance

b. Stock spare parts based on reliability, criticality, and cost: Station storage versus shuttle delivery.

c. Stress modular construction for replacement capability

d. Provide operational flight instrumentation and bulit-in test: Fault isolate to replaceable unit

e. Minimize EVA vehicle maintenance operations
    1. Consider safety in hazardous situations.
    2. Trade-off EVA versus support equipment.
        TV inspection
        Removal and replacement via teleoperations

Level I maintenance consists of the scheduled and unscheduled activities that occur on the vehicle while it is berthed in the Space Station maintenance hangar.

Level II maintenance encompasses the off-vehicle repair of replaceable OTV components conducted at the Space Station. The OTV replaceable units will be dispositioned for return to Earth or repaired at the station to the extent possible within the test equipment, spaces availability, and economic constraints.

Level III maintenance will involve normal Earth-oriented disposition for repair. An extensive analysis will ultimately provide the necessary repair or discard decision criteria.

Although three levels of maintenance were defined to understand the interrelationship of activities, the scope of the contract for this study requires that we look only at Level I maintenance activities at the Space Station.

The maintenance philosophy also stresses important maintainability features that an SBOTV must have, and these features affect the operations analysis with respect to task definitions and the time it takes to do them. These maintainability features have been incorporated into our conceptual designs of the SBOTV and Space Station, which include the modular concept for simple replacement of components. The modular configuration concept requires quick-disconnect interfaces and adequate built-in test capability to allow fault isolation to the replaceable unit.

Figure 4-4 summerizes the major turnaround functions. Each of these will be addressed in the following sections.

4.5.1 RENDEZVOUS AND PROXIMITY OPERATIONS. OTV will be capable of three retrieval methods as shown in Table 4-3. These methods are shown in more detail on following figures.

The OTV autonomous method uses the most OTV propellant which is the most expensive propellant because it has to be carried to GEO and back. This method also raises safety questions (unless astronaut surveillance and manual override is used) because an unmanned vehicle will be autonomously maneuvering in the vicinity of the manned space station. The advantages to this method are that it is operationally simple and requires only one interface, OTV to space station.

The OMV-assist method raises many questions. Is OMV capable of maneuvering an OTV? If not, what is the mechanical and electrical nature of the interface? Are OMVs antennas blocked by the aerobrake? These questions will be complicated when OTV returns with a payload or manned module. When OMV returns with OTV, two MRMSs and the OMV and OTV hangers will be in parallel operation. The advantages to this method are that only one spacecraft needs the rendezvous "smarts" and OMV retrieval operations should be routine be routine by the time OTV flies.

The tethered assist method is the farthest from implementation, but offers some unique advantages. This method uses the least propellant and would create very little, if any, plume impingement on the station. The 200 pounds of propellant required for station reboost could be eliminated by deboosting a Shuttle ET. A major disadvantage is that Space Station accelerations will be greater than 10^{-5}g until OTV is within 2 to 3 km.

This retrieval technique shown in Figure 4-5 involves only the OTV and space station and relies heavily on the global positioning system (GPS) for relative navigation.

OTVs precision navigation system (required for aeromaneuvering) will allow it to autonomously inject itself into an orbit 22 km behind the Space Station. OTV then uses GPS information from its onboard receiver (already baselined for navigation system use) and the Space Station's receiver (already baselined) to maneuver closer to Space Station. Activities on the Space Station during this time include: 1) sending GPS data to OTV over K-band link, 2) monitoring OTV subsystems status, and 3) tracking OTV with rendezvous radar and/or OTV GPS data.

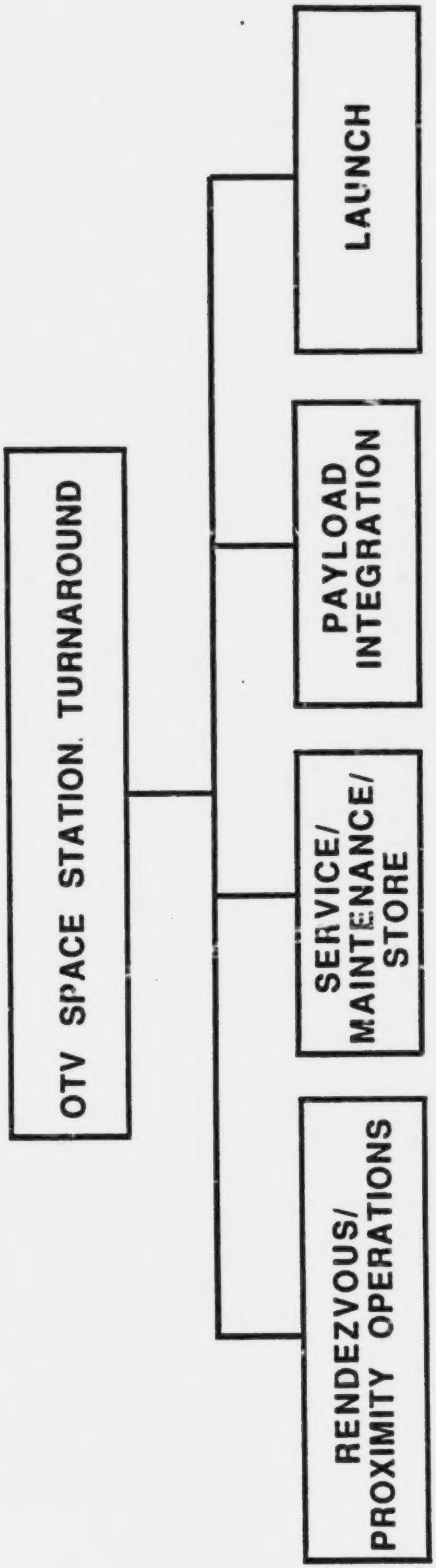
OTV SPACE STATION TURNAROUND
RENDEZVOUS/ PROXIMITY OPERATIONS
SERVICE/ MAINTENANCE/ STORE
PAYLOAD INTEGRATION
LAUNCH

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Figure 4-4. SBOTV Turnaround Operations Analysis

Criteria Options	Propellant required (lb)			Inert weight (lb)			Astronaut hr	Issues
	OTV	OMV	SS	OTV	OMV	SS		
OTV autonomous	260	0	0	10	0	0	7.3	Requires additional guidance & sequencing on OTV. RCS must operate in cold gas mode
OMV assist	0	740	0	0	0	0	12.	Requires mechanical & electrical OMV/OTV interface. Assume OMV capable of maneuvering/controlling OTV Complex operation. Communication link blockage. How will OMV attach when OTV returns with a payload? During launch?
Tethered assist	0	0	200	0	0	29,000	20	Requires Space Station reboost. Long tethertime places attitude constraints on OTV. Limited rendezvous window creates > 2 × 10^{-4}g's at SS. How will the tether end effector attach when OTV returns with a payload? During launch?

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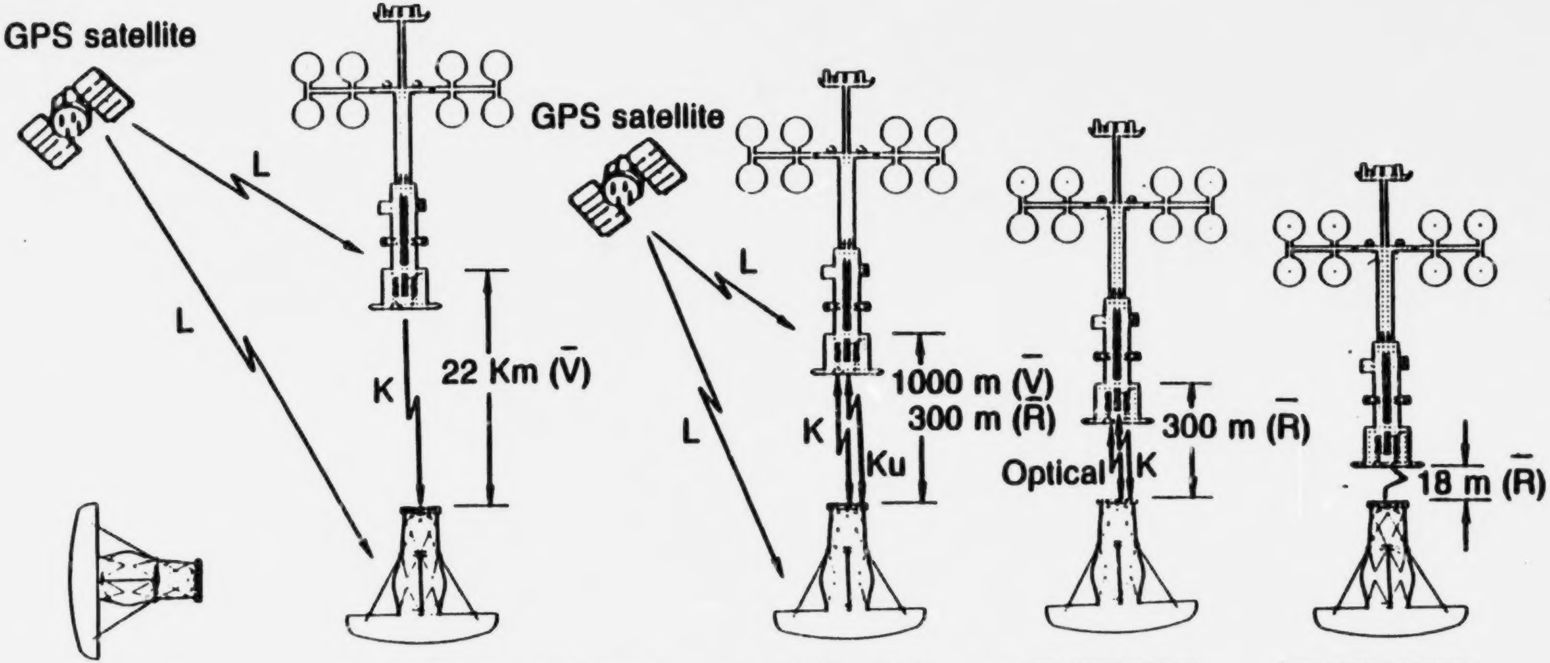
Table 4-3. OTV Rendezvous and Retrieval Operations Methods



- OTV ATTAINS
  - 500 Km APOGEE
  - 150 Km PERIGEE
  - AFTER AEROBRAKE
- OTV CIRCULARIZES TO 500 Km & ARRIVES AT OFFSET POINT 22 Km BEHIND SS

- OTV & SS UPDATE STATE VECTORS
- SS SENDS ITS POSITION TO OTV
- OTV BURNS TO CLOSE POSITION

- SS TRACKS OTV WITH RENDEZVOUS RADAR
- ASTRONAUT CAN TAKE MANUAL CONTROL AT ANY TIME

- OTV USES RCS TO CLOSE POSITION USING GPS RELATIVE NAVIGATION
- OTV SENDS OTV STATUS TO SS
- SS TRACK OTV WITH RENDEZVOUS RADAR

- OTV USES RCS TO CLOSE POSITION
- OTV SENDS OTV STATUS TO SS
- SS TRACKS OTV WITH OPTICAL SCANNER

- SS MRMS GRASPS OTV
- OTV IS BERTHED IN HANGAR

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Figure 4-5. Rendezvous and Proximity Operations: OTV Autonomous Retrieval

Once in the Space Station proximity, OTV's RCS will operate in a hydrogen-only mode to reduce plume contamination.

The final 300 meters of rendezvous will be done along R bar and the Space Station will track OTV retroreflectors with an optical scanner. At any time during the operations, an astronaut can take manual control of the OTV guidance system and be aided by OTV running lights, Space Station TV cameras, and optical scanner information.

Errors in the OTV navigation system can be overcome by the flexibility of the MRMS which has little attitude or position accuracy requirements for soft dock. After MRMS attachment, the OTV is put in dormant mode and the MRMS controls final berthing.

This retrieval technique shown in Figure 4-6 uses OMV to rendezvous and dock with OTV then return it to the space station.

How OMV will rendezvous with OTV and how it will rendezvous with the Space Station is unclear, so this picture has little detail but contains the basic steps. OMV will rendezvous with OTV in some orbit different than or co-orbiting with the station. OTV guidance will allow it to autonomously co-orbit with the station after aeromaneuvering. However, in order to save OTV propellant, the OTV could remain in a lower perigee orbit. OTV support during OMV/OTV rendezvous is assumed to be no more than running lights, retroreflectors, and possibly telemetering GPS information.

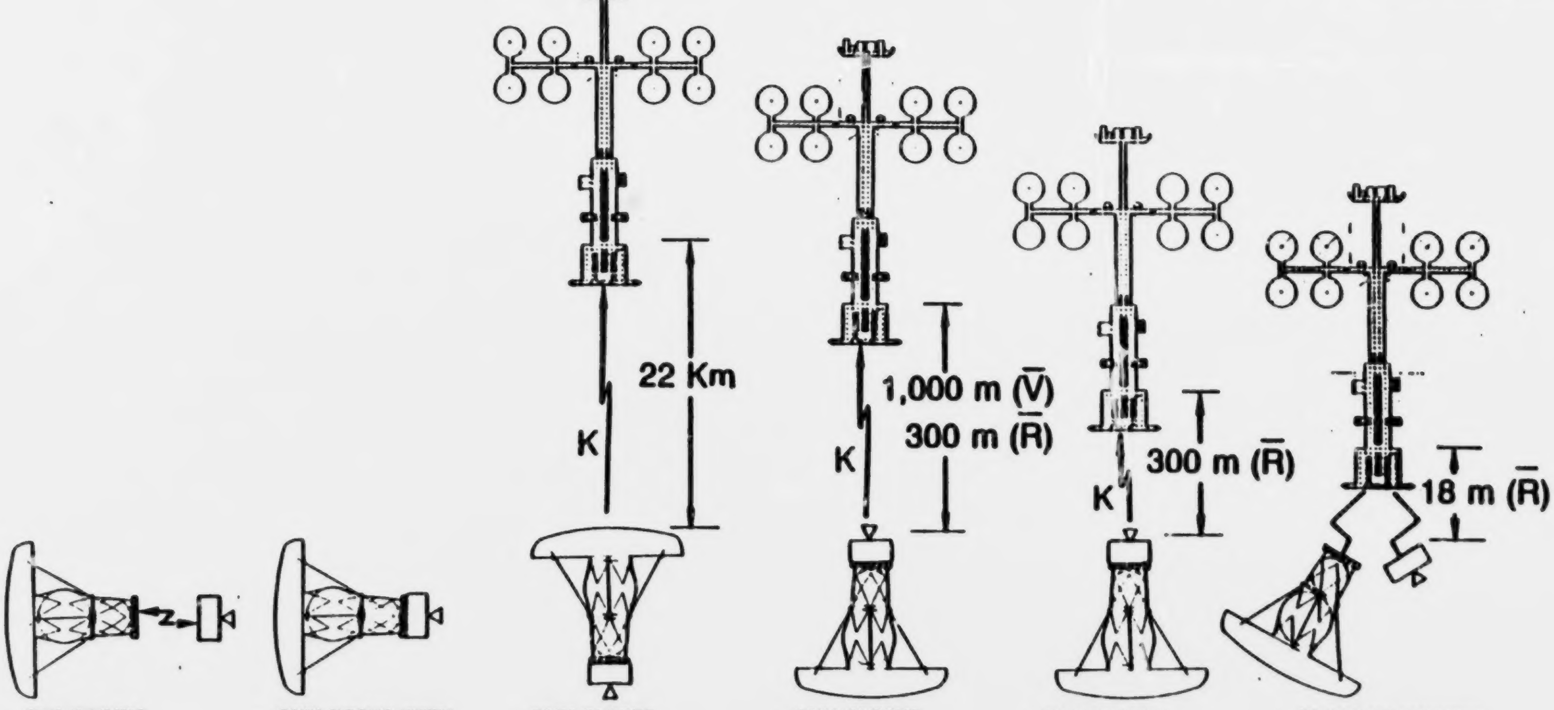
The OMV will then control the maneuvering of OMV and OTV to the vicinity of the station using its standard payload retrieval routine. OTV support requirements during this phase could be very different from OTV autonomous rendezvous requirements (i.e., if the OTV RCS or communication system must be used by OMV).

Once grappled by the MRMS, OMV and OTV will be separated and parallel OMV/OTV berthing and stowing operations begins.

Tethered retrieval of OTV shown in Figure 4-7 uses a 50-km-long tether with a smart end effector to capture and retrieve OTV.

The end effector/OTV rendezvous takes place at the apogee of OTVs 450 by 150 km orbit and has a limited capture window as OTV falls away and speeds up to perigee. The smart end effector will be an OMV-type device with rendezvous sensors, attitude control system, and docking mechanisms. The end effector will be able to maneuver and dock on a limp tether until docking, when the tether will become taut. OTV support during tether rendezvous will be running lights, retroreflectors, and possibly telemetered GPS information.

The OTV can be placed in a dormant mode while the tether is reeled in. During that time, the end effector must damp oscillations in the tether. The end effector must also keep the tether taut when tensions in the tether become minimal at close distances to the Space Station. The end effector must then brake closure rates between OTV and the station when it is inside MRMS reach.



- OTV ATTAINS
  - 500 Km APOGEE
  - 150 Km PERIGEE
- OMV ATTAINS SAME ORBIT
- OMV TRACKS OTV

OR

- OTV CIRCULARIZES TO 500 Km, 40 Km BEHIND SS
- OMV TRACKS OTV

- OMV DOCKS WITH OTV (GROUND CONTROLLED)
- OMV CIRCULARIZES ORBIT TO 500 Km

OR

- OMV DOCKS WITH OTV (GROUND OR SS CONTROLLED)

- OMV CLOSES POSITION WITH SS
- OMV/OTV SEND OMV/OTV STATUS TO SS
- ASTRONAUT CAN TAKE MANUAL CONTROL AT ANY TIME

- OMV CLOSES POSITION
- OMV/OTV SEND OMV/OTV STATUS TO SS

- OMV CLOSES POSITION
- OMV/OTV SEND OMV/OTV STATUS TO SS

- SS MRMS GRASPS OMV & OTV
- OMV & OTV ARE SEPARATED & BERTHED

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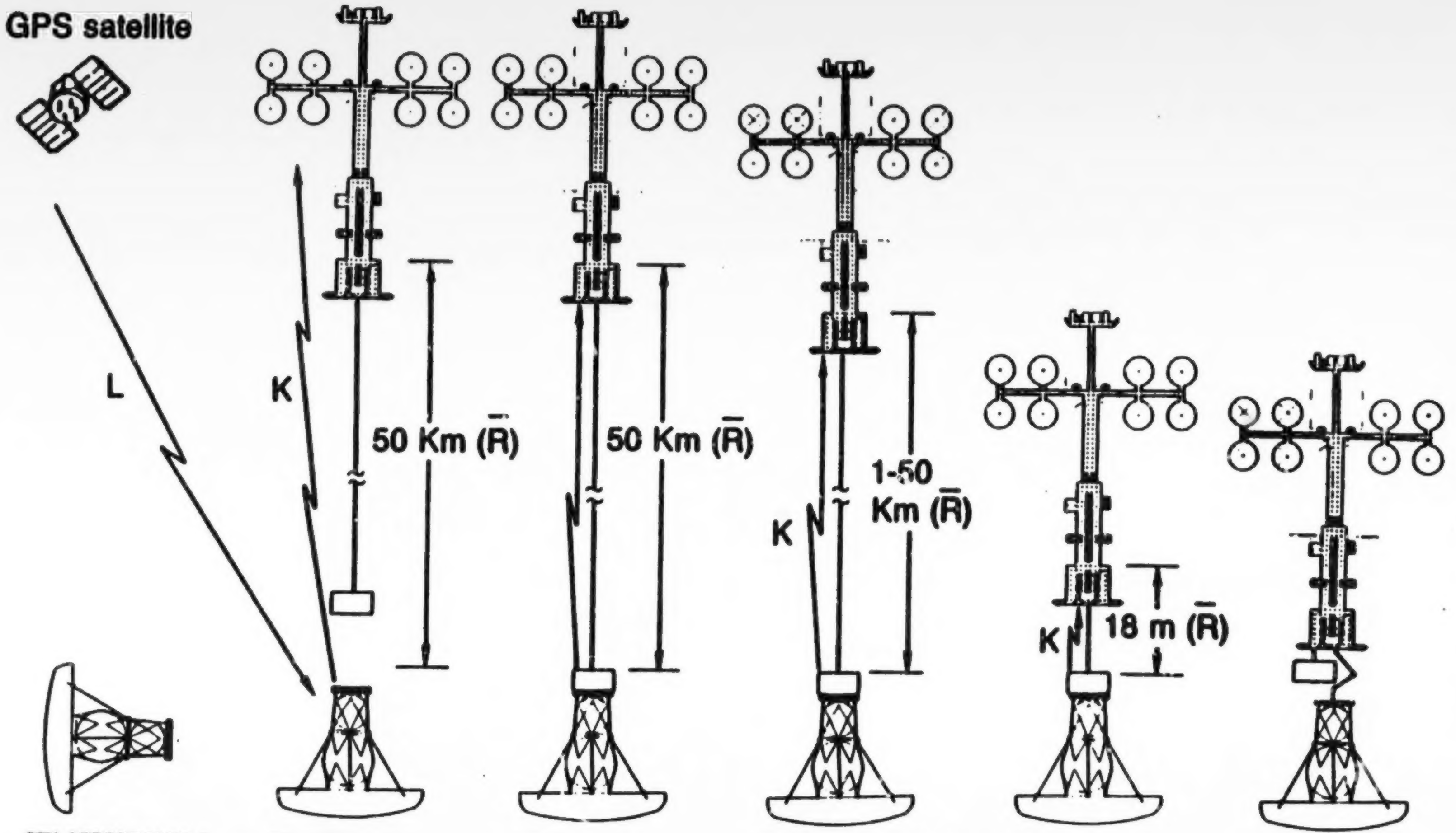
Figure 4-6. Rendezvous and Proximity Operations: OTV Assist Retrieval



- OTV AEROBRAKES & ATTAINS

  450 Km APOGEE
  150 Km PERIGEE

- OTV SENDS ITS POSITION & STATUS TO SS
- TETHER SMART END EFFECTOR CLOSES POSITION

- SMART END EFFECTOR DOCKS WITH OTV
- END EFFECTOR DAMPS TETHER OSCILLATIONS
- OTV SAFED

- OTV IS REELED IN ON TETHER
- OTV SENDS OTV STATUS TO SS
- END EFFECTOR KEEPS TENSION IN TETHER

- SMART END EFFECTOR BRAKES CLOSURE
- OTV SENDS OTV STATUS TO SS

- MRMS GRASPS OTV
- OTV SEPARATED FROM END EFFECTOR & BERTHED

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The Space Station will lose over a kilometer of altitude in the procedure. This can either be allowed, compensated for with a station propulsive reboost, or compensated for with a tethered deboost of an object such as the Orbiter or external tank.

OTV should be compatible with all three retrieval methods. Each method has advantages and disadvantages and can back up the other. OMV (and probably the tether) will be available at the station and will be used if an OTV failure (i.e., RCS or communications) precludes autonomous rendezvous. If OMV is busy or failed, the OTV and tethered assist capability ensure flexible station operations. Since tethered operations can take over 24 hours, OMV assist and OTV autonomous retrieval should be available in case of a busy, failed, or non-existent tether. It is conceivable that the Space Station temporarily could not support an operation requiring the manhours that OTV needs during and after retrieval. In that case, the OMV or tether could support a dormant OTV that is not designed for long on-orbit stays at the end of its mission.

The primary mode of retrieval is OTV autonomous because it has the shortest duration and requires the least manhours. This operation will not require the OTV to interface with multiple vehicles such as the OMV or tether and the Space Station at the same time. Also, the primary mode of retrieval is sensitive to the primary mode of launch, and the OMV or tether may not be able to attach to OTV when it carries a payload during launch.

Tethered retrieval operations need to be investigated in more detail, especially the crew requirements. Since the operations can last over a day, crew monitoring and activities must be evaluated.

Questions remain as to where and what type of sensors should be used. Is GPS-relative navigation good enough for OTV to maneuver within MRMS reach? If not, can the station's optical scanner data be sent to OTV or does OTV need its own sensor? Do cameras need to be located on OTV for manual operations?

The capability for the OMV RCS to maneuver OTV without OTV help must be evaluated. If OMV needs OTV RCS help, the physical and electronic nature of the OMV/OTV electrical interface needs to be determined.

4.5.2 PAYLOAD INTEGRATION. The payload integration trade tree (see Figure 4-8) shows the recommended paths that were established from the trade studies that were conducted to assess the major accommodations and operations alternatives for payload integration operations.

The payload integration trade comparison table (see Table 4-4) presents the five operation/accommodation options horizontally and the evaluation criteria in the vertical columns. The recommended option has the lowest cost mainly because it does not require a new crew module-to-station interface inside the OTV hangar. The selected options allow the crew to transfer into the crew module direct from a station module and the crew module is then transported to the OTV with the crew onboard. The OTV's fueling interface is also outside of the hangar.

4.5.3 LAUNCH. The OTV launch trade study (see Figure 4-9) is closely related to the OTV retrieval trade study except that procedures are reversed. Both operations analyses concluded the same results. OTV autonomous control is

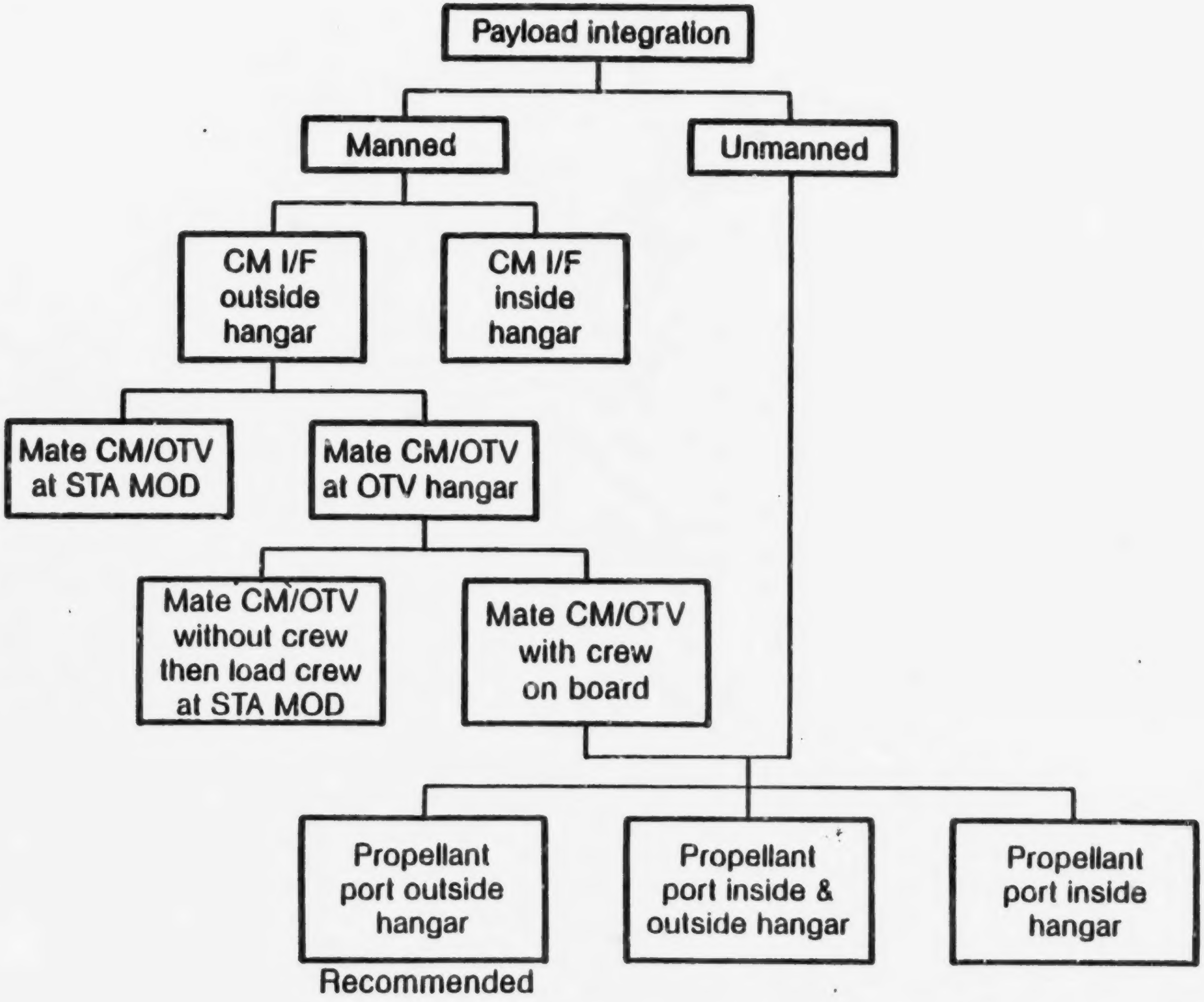
Payload integration
Manned
Unmanned
CM I/F outside hangar
CM I/F inside hangar
Mate CM/OTV at STA MOD
Mate CM/OTV at OTV hangar
Mate CM/OTV without crew then load crew at STA MOD
Mate CM/OTV with crew on board
Propellant port outside hangar
Recommended
Propellant port inside & outside hangar
Propellant port inside hangar

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Figure 4-8. Operations Analysis Trade Tree: Payload Integration

OPTION / CRITERIA	• CM/STA I/F IN OTV HGR • PROP XFER IN HGR	• CM/STA I/F NOT IN OTV HGR • PROP XFER NOT IN HGR • MATE AT HGR CREW ON BOARD	• CM/STA I/F NOT IN HGR • PROP XFER NOT IN HGR • MATE AT STA MODULE	• CM/STA I/F NOT IN OTV HGR • PROP XFER NOT IN HGR • MATE AT HGR THEN XFER CREW AT STA MOD	• CM/STA I/F IN OTV HGR • PROP XFER NOT IN HGR
CREW TIME IN MODULE	1:20	2:50	1:20	1:20	1:20
ELAPSED TIME	9:15	9:10	10:40	12:25	9:45
MANHOURS/OPERATION	12:30	13:40	15:20	18:45	13:30
TOTAL MH (28 MISSIONS)	350	383	429	525	378
MANHOUR COST ($M)	66	72	80	98	71
CM/STA I/F IN HGR ($M)	35	---	---	---	35
TOTAL OPS COST ($M)	101	72 ✓	80	98	106

NOTE: ALL CREW TRANSFERS ARE IVA ✓ RECOMMENDED

Table 4-4. SBOTV Payload Integration Trade Study: Manned Payload

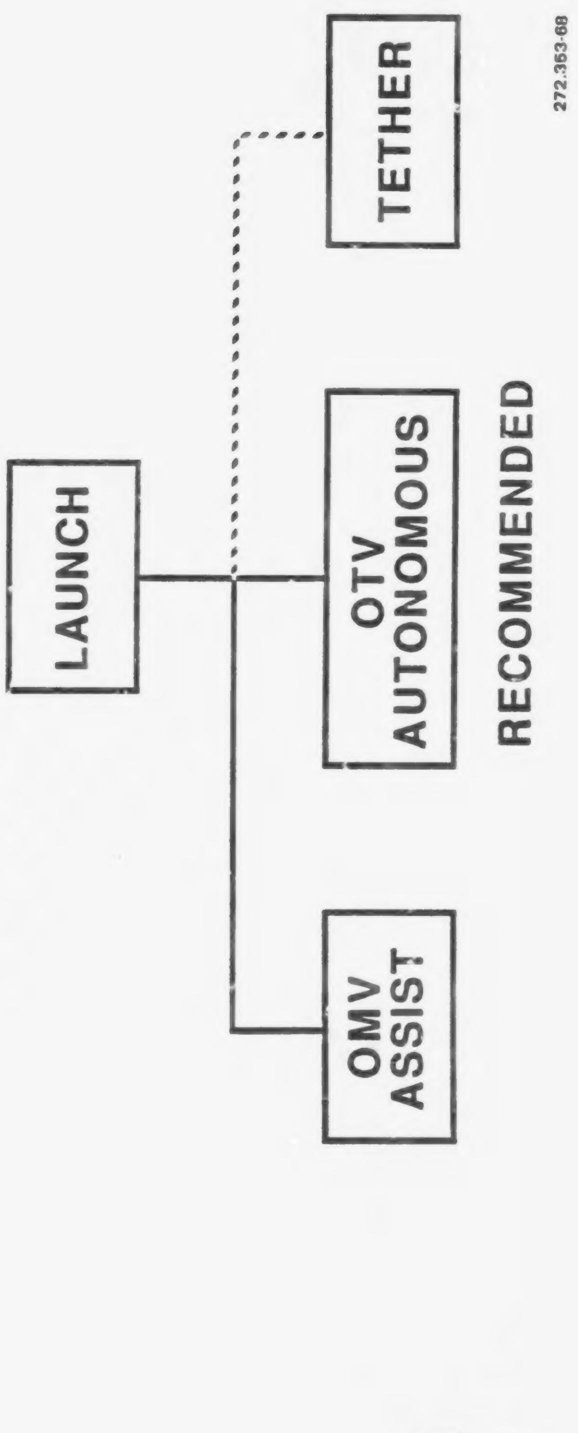

Figure 4-9. Operations Analysis Trade Tree: Launch

recommended over the use of OMV to maneuver the OTV to the mission hand-off point. Tethering is a likely candidate, but was not fully assessed at this time.

The recommended approach for OTV/payload integration and other operations at the Space Station is as follows:

a. OTV control for proximity operations: Reduces manpower requirements, complexity, and cost.

b. Crew module to station module interface outside OTV hangar: EVA crew translated to hangar via guide wires, rails, etc.

c. Stationary propellant port outside hangar: Configuration does not interfere with maintenance activities inside hangar.

d. Berth OTV at payload interface to rotary device inside hangar

   1. Rotary device provides access to OTV components.

   2. Berthing at payload interface does not require adjustments to various vehicle configurations.

   3. RMS is adequate to translate OTV in and out of hangar.

e. Two RMSs For Hangar Operations

   1. Two RMSs required for maintenance.

   2. One RMS could be used for OTV retrieval and launch.

4.5.4 SERVICING, MAINTENANCE, AND STORAGE. Figure 4-10 shows the trades that were performed to determine the best methods for maintenance, both scheduled and unscheduled. The analysis considered how the tasks should be performed, manually or with teleoperation and, if by teleoperation, whether or not the vehicle should release the components automatically.

Shown on Table 4-5 are additional ground rules to be used in the analysis and trade studies of the OTV turnaround operations at the station. The significant ones are the cost of the IVA and EVA for the crewmen.

To establish credible task times for both teleoperations tasks and EVA/IVA tasks we have used the following data shown as references:

a. Hamilton standard subcontract to OTV servicing study.

b. JSC-10615, SIS EVA description and design criteria.

c. SPAR aerospace limited: RMS operations.

d. Shuttle space operations data - RMS and EVA.

e. Rocketdyne: Engine maintenance design for space operations.

f. Skylab: EVA contingencies.

g. MSFC neutral buoyancy tank data.

We have tried to stay abreast of the evolving data on IVA/EVA capability coming from the Shuttle flights. The performance that can be achieved with the new space suits was obtained from Hamilton Standard.

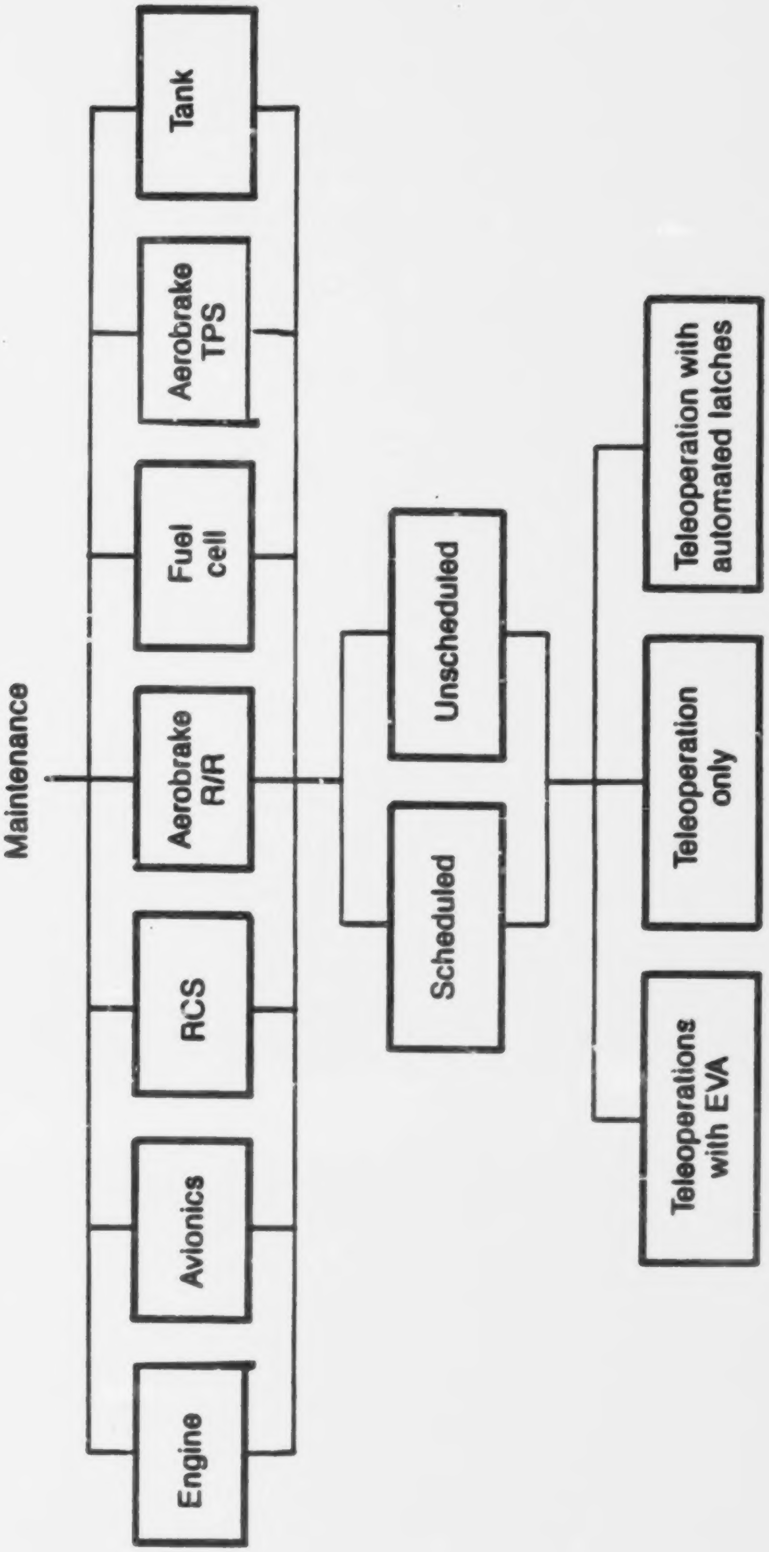

Figure 4-10. Servicing/Maintenance Operations Trade Tree

Space Station will be at 250 nmi when Shuttle docking occurs

Space Station growth will permit limited support of OTV in 1995 and full space basing in 1996.

Space Station keel width is 35 meters with a 5-meter truss bay

Space Station services:

Service	Charge ($FY-86)
ECLSS	$ 1.940k/crew hour
Propulsion	$ 0.0055k/sq ft drag per day
Airlock	$119.965k/(egress + ingress)
Heat rejection	$ 0.022k/kWhr
Manipulator	$ 35.869 k/ops hour
Data management	$ 0.0055k/channel hour
Comm & tracking	$ 0.234 k/channel hour
EVA	$ 81.715k/crew hour × 2 (min) = $163.430 k/hr/EVA*
IVA	$18.723 k/crew hour
Energy	$ 0.151k/hWhr
OTV storage/service facility	$250 k/flight
OMV storage/ service facility	$250 k/flight
Payload servicing	$271 k/event

OTV must minimize venting in the vicinity of Space Station to remain within allowable contamination limits. Space Station is assessing the utilization of boil-off gasses and controlled venting.

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* This is based on a new suit (not part of IOC station)

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Table 4-5. Major Ground Rules for SBOTV

The selection criteria which will be used in the servicing/maintenance trade studies are shown in Table 4-6. They include design, operations, and cost factors.

4.5.4.1 Aerobrake TPS: Table 4-7 is an example of the task analysis sheets we have develcped for all of the turnaround tasks. These sheets contain a description of the tasks to be performed, the support equipment requirements, the task duration, IVA/EVA time, and whether it is a direct task or a supporting task, and the total manhours for the task including the EVA manhours.

The subtasks are quite detailed so that a comprehensive understanding of what is being accomplished can be obtained.

Figure 4-11 shows the method for aerobrake TPS replacement that was developed in conjuction with the task analysis. Task analysis data is used to establish the task duration and manhour times that are used in the trade comparisons.

Due to the complexity and accessibility of the aerobrake, it is recommended that this task be performed using an EVA crew. The time established requires that both crew members attach aerobrake spacers to the frame simultaneously.

Let it be noted that this is the only task identified where two EVA crew members were actually required to accomplish the task. All other EVA operations only require one EVA crew member to do the job, however we included the second crew member in all of the EVA task analyses, because it is a requirement.

Table 4-8 shows the times for removal and replacement of the aerobrake TPS established for the three types of aerobrakes used on the different OTV concepts. Although the aerobrakes will vary in size, removal and replacement time will not change significantly, because the number of attachment nodes determine the task time.

4.5.4.2 Aerobrake. Table 4-9 shows the aerobrake removal and replacement trade comparison for the three maintenance options. Aerobrake removal and replacement is required for accessibility for other maintenance tasks.

The criteria used for selection of a recommended option included support equipment requirements, vehicle design requirements, task duration, manhour requirements (EVA and total), vehicle weight differences, advanced technical development, accessibility, maintainability, reliability, and cost.

The cost analysis includes production and delivery cost for all hardware development. It also includes operations costs and any penalty for added weight on the OTV. The low-mission model was used for this comparison.

The results of this comparison indicate the use of the "teleoperation only" option for performing the aerobrake removal and replacement task. This option conserves manpower while holding cost at a minimum.

CRITERIA	COMMENTS
SUPPORT EQUIPMENT/FACILITIES	DESCRIPTION
VEHICLE DESIGN REQUIREMENTS	DESCRIPTION
TASK DURATION - HRS	TOTAL TIME PER TASK
MANHOURS	CRITICAL RESOURCE COMMODITY
GROUND ______	
IVA ______	
EVA ______	
TOTAL ______	
MANHOUR COST - $	LIFE CYLE
VEHICLE WEIGHT (DELTA) - LB	VEHICLE PERFORMANCE CAPABILITY PER MISSION
TECHNICAL DEVELOPMENT	DESCRIPTION
ACCESSIBILITY REQUIREMENTS - FT^3	VOLUME
VEHICLE COMPLEXITY	DESCRIPTION
VEHICLE RELIABILITY	
LIFE CYCLE COST - $	

Table 4-6. SBOTV Trade Study Selection Criteria

SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	TASK DURATION	IVA DIRECT	IVA REMOTE	SUPRT	EVA ACTIVE	EVA STDBY	MAN HOURS TOTAL	MAN HOURS EVA
SCHEDULED MAINTENANCE R/R AEROBRAKE TPS FOR STRUT GEOTRUSS AEROBRAKE (77 NODES)		19.06						54.38	25.52
DAY -1-		9.11						26.23	12.22
o ACTIVATE SYSTEM AND REVIEW PLAN		1.00						2.00	0.00
-Query computer and review maintenance plan	-Computer system	0.30	3					1.30	0.00
-Bring all systems on line	-Facility controls	0.30		1				0.30	0.00
o PRE-EVA ACTIVITIES		1.15						2.30	0.30
-Perform PRE-EVA tasks	-EMU, Airlock	1.00	2					2.00	0.00
-Translate EVA crew to OTV hangar	-Guide wires and hand holds	0.15				2		0.30	0.30
o REMOVE AEROBRAKE DOOR	PT	1.05						1.05	0.00
	!	Parallel with Pre-EVA activities							
-Activate and position RMS		0.05		1				0.05	0.00
-Grasp aerobrake door		0.10		1				0.10	0.00

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Table 4-7. Maintenance: Aerobrake TPS-Strut Geotruss

SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	TASK DURATION	IVA DIRECT	IVA REMOTE	IVA SUPRT	EVA ACTIVE	EVA STDBY	MAN HOURS TOTAL	MAN HOURS EVA
with RMS									
-Disconnect hinge brackets 3 places		0.15		1				0.15	0.00
-Unlatch door 2 places		0.10		1				0.10	0.00
-Translate EVA crew to safe area		0.05		1				0.05	0.00
-Translate aerobrake door to storage area		0.05		1				0.05	0.00
-Position aerobrake door in holding fixture and latch		0.10		1				0.10	0.00
-Release RMS		0.05		1				0.05	0.00
o REMOVE AEROBRAKE TPS		5.41						17.03	11.22
-Position EVA crew		0.05				1	2	0.15	0.10
-Disconnect TPS outside edge		0.05				1	2	0.15	0.10
-Grasp spacer & release		(.01)							
-Fold back TPS edge		(.02)							
-Reposition EVA crew		(.01)							
-Repeat disconnect outside edge eleven times		0.44				1	2	2.12	1.28
-Attach packing tool	-Packing tool	0.10				1	2	0.30	0.20

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Table 4-7. Maintenance: Aerobrake TPS-Strut Geotruss, Contd

		TASK	¦-----	IVA	-----¦	¦--- E V A --¦		MAN HOURS	
SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	DURATION	DIRECT	REMOTE	SUPRT	ACTIVE	STDBY	TOTAL	EVA
-Attach packing tool (one end)		(.03)							
-Position EVA crew		(.01)							
-Attach packing tool (other end)		(.03)							
-Reposition EVA crew		(.03)							
-Repeat attach packing tool		0.10			1	2		0.30	0.20
-Disconnect spacer		0.02			1	2		0.06	0.04
-Grasp spacer and release		(.01)							
-Reposition EVA crew		(.01)							
-Repeat Disconnect		0.02			1	2		0.06	0.04
-Fold TPS-activate tool mechanism		0.05			1	2		0.15	0.10
-Attach TPS packing strap		0.10			1	2		0.30	0.20
-Reposition Packing tool two places		0.10			1	2		0.30	0.20
-Repeat disconnect spacer three times		0.06			1	2		0.18	0.12
-Fold TPS		0.05			1	2		0.15	0.10
-Attach TPS packing strap		0.10			1	2		0.30	0.20
-Reposition packing tool two places		0.10			1	2		0.30	0.20

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Table 4-7. Maintenance: Aerobrake TPS-Strut Geotruss, Contd

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		TASK	IVA			E V A		MAN HOURS	
SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	DURATION	DIRECT	REMOTE	SUPRT	ACTIVE	STDBY	TOTAL	EVA
-Repeat disconnect spacer three times		0.06			1	2		0.18	0.12
-Fold TPS		0.05			1	2		0.15	0.10
-Attach TPS packing strap		0.10			1	2		0.30	0.20
-Reposition packing tool two places		0.10			1	2		0.30	0.20
-Repeat disconnect spacer four times		0.08			1	2		0.24	0.16
-Attach TPS packing strap		0.10			1	2		0.30	0.20
-Release packing tool		0.05			1	2		0.15	0.10
-Repeat attach packing tool		0.10			1	2		0.30	0.20
-Repeat disconnect spacer three times		0.06			1	2		0.18	0.12
-Fold TPS		0.05			1	2		0.15	0.10
-Attach TPS packing strap		0.05			1	2		0.15	0.10
-Reposition packing tool		0.05			1	2		0.15	0.10
-Repeat disconnect spacer three times		0.06			1	2		0.18	0.12
-Fold TPS		0.05			1	2		0.15	0.10
-Attach TPS packing strap		0.05			1	2		0.15	0.10
-Reposition packing tool		0.05			1	2		0.15	0.10
-Repeat disconnect spacer		0.08			1	2		0.24	0.16

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Table 4-7. **Maintenance:** Aerobrake TPS-Strut Geotruss, Contd

SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	TASK DURATION	IVA DIRECT	IVA REMOTE	IVA SUPRT	E V A ACTIVE	E V A STDBY	MAN HOURS TOTAL	MAN HOURS EVA
four times									
-Fold TPS		0.05			1	2		0.15	0.10
-Attach TPS packing strap		0.05			1	2		0.15	0.10
-Release packing tool		0.05			1	2		0.15	0.10
-Repeat attach packing tool		0.10			1	2		0.30	0.20
-Repeat disconnect spacer		0.02			1	2		0.06	0.04
-Fold TPS		0.05			1	2		0.15	0.10
-Attach TPS packing strap		0.05			1	2		0.15	0.10
-Reposition packing tool		0.05			1	2		0.15	0.10
-Repeat disconnect spacer		0.02			1	2		0.06	0.04
-Fold TPS		0.05			1	2		0.15	0.10
-Attach TPS packing strap		0.05			1	2		0.15	0.10
-Release packing tool		0.05			(1)	2		0.10	0.10
-Activate and position RMS		0.05			1		(2)	0.05	0.00
-Grasp TPS		0.05			1	2		0.15	0.10
-Repeat disconnect spacer two times		0.04			1	2		0.12	0.08
-Transfer TPS to storage area		0.15		1			2	0.45	0.30
-Attach TPS to storage fixture	-Storage fixture	0.05		1			2	0.15	0.10

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Table 4-7. Maintenance: Aerobrake TPS-Strut Geotruss, Contd

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			TASK	¦-----	IVA -----¦	¦--- E V A	--¦	MAN HOURS	
SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS		DURATION	DIRECT	REMOTE	SUPRT	ACTIVE	STDBY	TOTAL	EVA
-Release RMS & stow		P	0.05		1			(2)	0.05	0.00
-Translate crew to hangar opening		¦	0.05			(1)	2		0.10	0.10
o POST EVA ACTIVITIES			1.15						3.45	0.30
-Transfer EVA crew to station module			0.15			1	2		0.45	0.30
-Perform POST-EVA tasks	-EMU refurbish facility	¦	1.00	2		1			3.00	0.00
o DEACTIVIATE ALL SYSTEMS		¦	0.00						0.00	0.00
-Deactiviate all systems and secure		P	0.15		(1)				0.00	0.00

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Table 4-7. Maintenance: Aerobrake TPS-Strut Geotruss, Contd

4.5.4.3 Engine. Panel disconnects with automatic latching systems (see Figure 4-12) are being considered for the major systems of the OTV, such as the outrigger tanks and engines in order to reduce removal/replacement and OTV turnaround time. These panel-latching systems will allow the mating of a structure and several fluid and electrical lines in a single operations, thus reducing maintenance time.

An example of a cryogenic disconnect mounted on an interface panel is also depicted. It consists of a poppet valve to seal the coupling upon panel disconnect, and it also contains redundant bellows to prevent the escape of any propellants during a mission.

Table 4-10 shows the engine removal and replacement trade comparison for the three maintenance options. This data is for the removal and replacement of both engines.

The criteria used for selection of a recommended option included support equipment requirements, vehicle design requirements, task duration, manhour requirements (EVA and total), vehicle weight differences, advanced technical development, accessibility, maintainability, reliability, and cost.

The cost analysis includes production and delivery costs for all hardware development. It also includes operations costs and any penalty for added weight on the OTV. The Rev. 8 nominal mission model was used for this comparison.

The results of this comparison indicates the use of the "teleoperation only" option for performing the scheduled engine removal and replacement task. This option conserves manpower while holding cost at a minimum.

4.5.4.4 Avionics/Fuel Cell. Depicted in Figure 4-13 is a concept for arranging the avionics modules around a central, flat, 10-sided ring. This concept allows accessibility for removal by EVA or robotics. The modules can be removed/replaced by utilizing guide tubes and retention latches (similar to the multimission spacecraft), to accommodate the Universal Service Tool System. One central electrical connector on the aft face of each module would mate with a connector out of the central electrical cable way circumscribing the core structure. The core avionics structure is also removable to allow major changes to the entire avionics system.

The payload adapter system consists of a multiple payload carrier (MPC) mounted to the avionics structure and single payload adapters used to enable the mating of differing payloads to the MPC. In the event of the OTV launching a single payload, the MPC can be easily removed and the single-payload adapter is attached directly to the directly to the avionics structure to save weight.

Table 4-11 shows the comparison for the removal and replacement of avionics modules and fuel cells.

The results of this comparison indicates the use of the "teleoperation only" option for performing the unscheduled avionics module or fuel cell removal and replacement task. This option conserves manpower and adds no cost to the vehicle.

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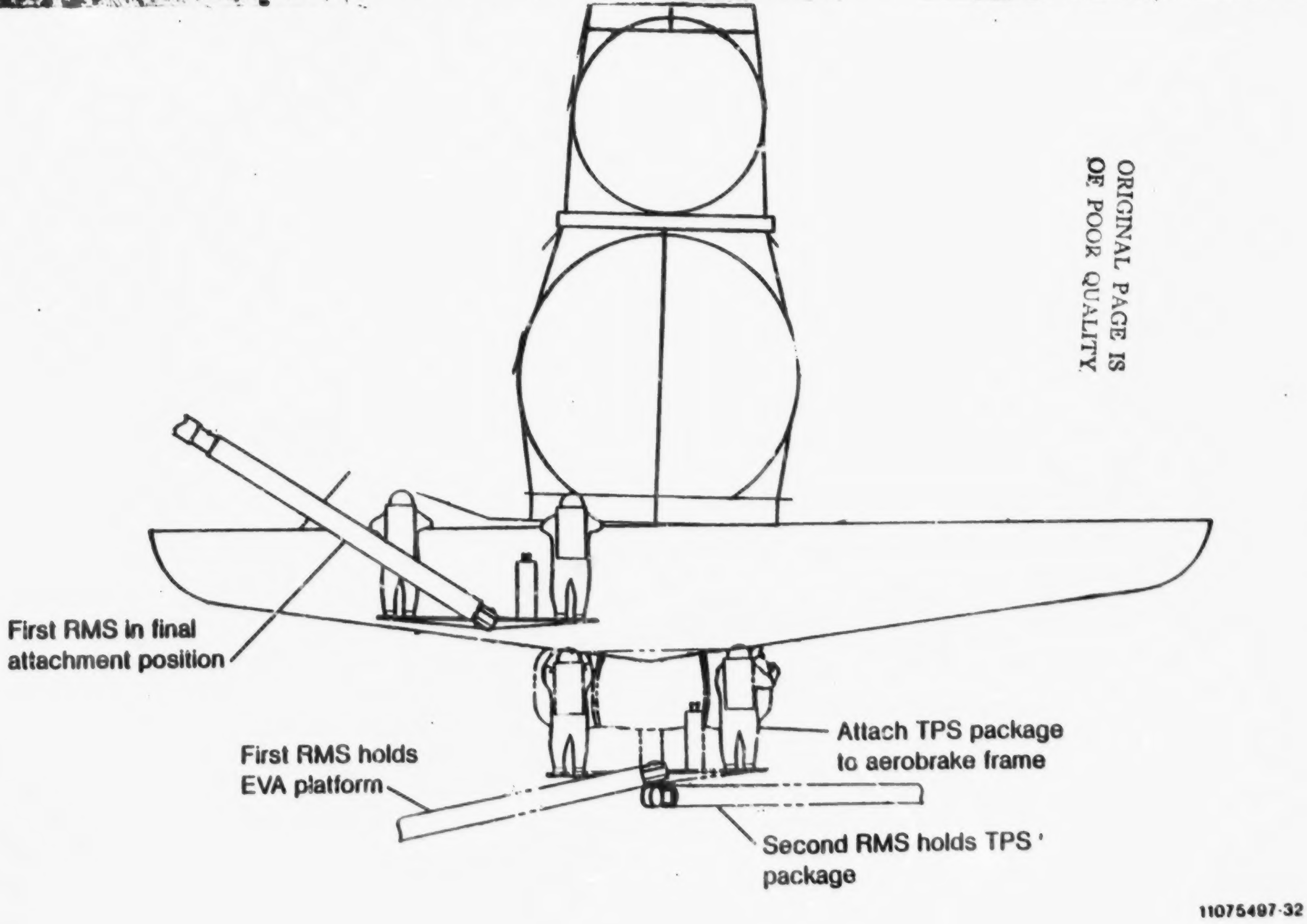
First RMS in final attachment position
First RMS holds EVA platform
Attach TPS package to aerobrake frame
Second RMS holds TPS package
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Figure 4-11. Aerobrake TPS Replacement Operations

Aerobrake	Task duration	Total manhours	EVA hours
Geotruss (45 nodes)	14:41 (2 days)	43:49	19:12
Strut geotruss (72 nodes)	17:51 (2 days)	53:18	25:32
Telescoping truss (56 nodes)	16:03 (2 days)	46:24	20:56

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Table 4-8. Remove and Replace Aerobrake TPS (EVA)

CRITERIA \ OPTION		TELEOPERATION WITH EVA	TELEOPERATION ONLY	TELEOPERATION WITH AUTOMATED LATCHES
SUPPORT EQUIPMENT REQUIREMENTS		2 RMS - 1 crew support adapter - 1 grasping adapter EVA support equipment	2 RMS - 1 servicing tool adapter - 1 grasping adapter	1 RMS - 1 grasping adapter
VEHICLE DESIGN REQUIREMENTS		OTV modular design EVA compatible disconnect	OTV modular design EVA/teleoperator compatible disconnect	OTV modular design Automated disconnect
TASK DURATION		7:55	5:35	3:20
MANHOURS	EVA	10:10	---	---
	TOTAL	22:55	5:35	3:20
MANHOUR COST(NMM)		133.8M	13.8M	8.2M
△ VEHICLE WEIGHT PER MISSION		Baseline	Same	+63 lb
REQUIRE TECHNICAL DEVELOPMENT		No	Minimal	Yes
ACCESSIBILITY REQUIREMENT		Crew: 4 ft x 5 ft x 6.5 ft RMS : 28 in. dia	Crew: none RMS : 2 ea. 28 in. dia	Crew: none RMS : 28 in. dia
VEHICLE COMPLEXITY		Baseline	Same	Increased - Hardware - Software
VEHICLE RELIABILITY		Baseline	Same	Decrease
COST (REV 8 NMM)		350M	143M	241M

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Table 4-9. Remove and Replace Aerobrake Trade Comparison

Panel disconnects are being developed to support modular propellant feed system design and simplify maintenance

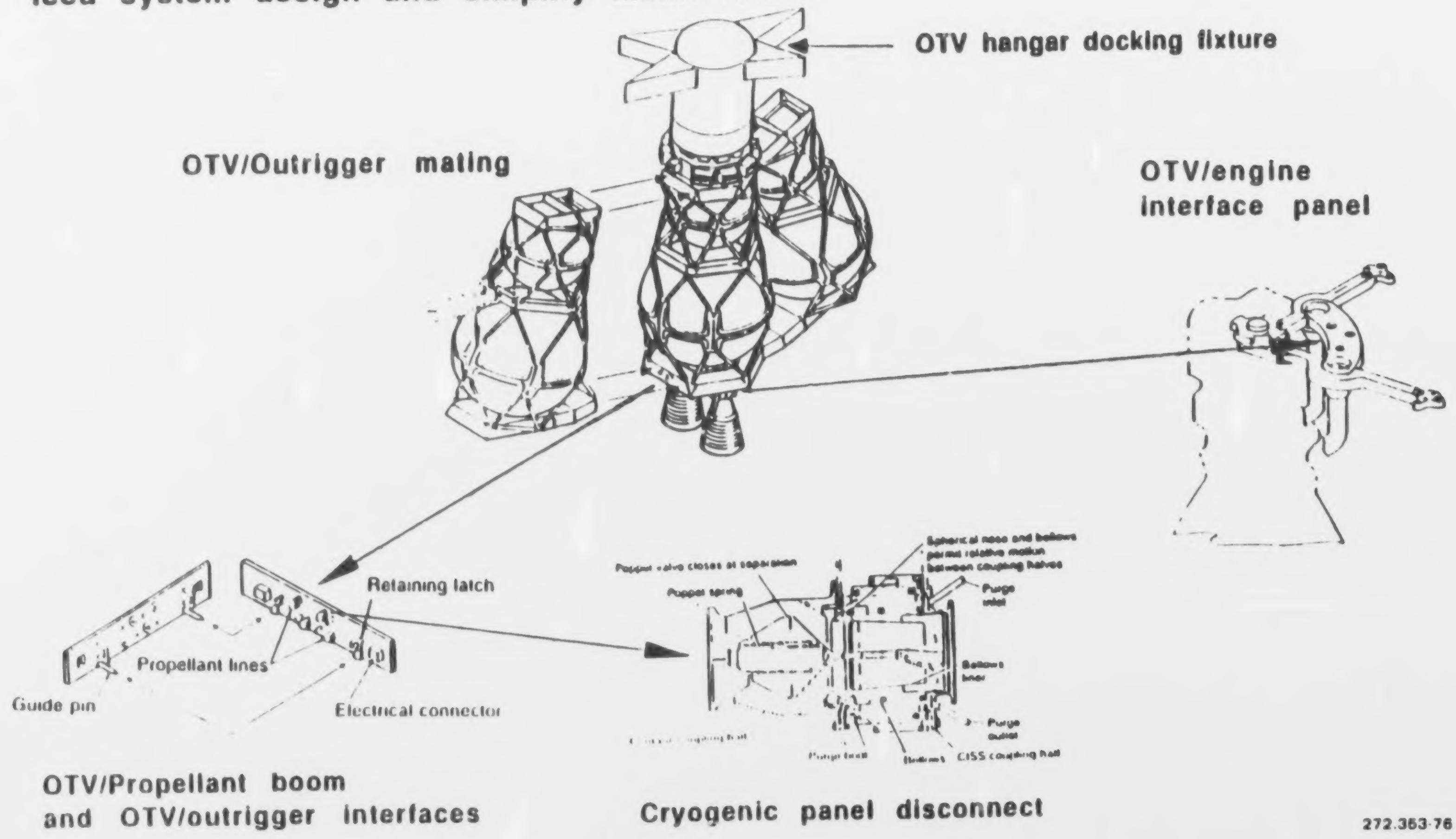
OTV hangar docking fixture
OTV/Outrigger mating
OTV/engine interface panel
Retaining latch
Propellant lines
Guide pin
Electrical connector
OTV/Propellant boom and OTV/outrigger interfaces
Poppet valve closes at separation
Poppet spring
Spherical nose and bellows permit relative motion between coupling halves
Purge inlet
Bellows liner
Purge outlet
Purge seal
Bellows
CISS coupling half
Cryogenic panel disconnect
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Figure 4-12. Propellant Disconnects

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Table 4-12 shows the comparison for the removal and replacement of RCS thrusters.

The results of the comparison indicates the use of the "teleoperation only" option for performing the unscheduled RCS thruster and replacement tasks. This option conserves manpower and adds no cost to the vehicle.

4.5.4.6 Propellant Tanks. Table 4-13 shows the propellant tank removal and replacement trade comparison for the three maintenance options.

The results of this comparison indicates the use of the "teleoperation only" option for performing removal and replacement. This option conserves manpower while holding cost at a minimum.

4.5.4.7 Comparison/Recommendation. Besides the crew at the Space Station, support people are required on the ground to perform the turnaround operations.

Table 4-14 compares the manhour time of the three maintenance options for all tasks predicted for the SBOTV using the nominal-mission model.

Tank stage reconfiguration, engine replacement, and aerobrake TPS replacement are scheduled maintenance tasks while the RCS, avionics, fuel cell, and propellant tank replacements are unscheduled tasks.

The tank set reconfiguration frequency is an average value. It was assumed that the OTV would perform two missions between reconfigurations.

The recommended "teleoperations only" option requires an average of 61 manhours in space with 8.2 percent being EVA hours. It also require 754 manhours of ground support personnel.

The following summarizes the recommended method of performing the operations required for an OTV at the Space Station:

a. Recommended
   1. Aerobrake remove and replace-teleoperation.
   2. Aerobrake TPS replacement-EVA with teleoperation.
   3. Engine remove and replace-teleoperation.
   4. Tank set remove/replace and reconfiguration-teleoperation.
   5. Avionics/fuel cell/RCS remove and replace-teleoperation.

b. Justification
   1. Trade comparison results-manhours, vehicle penalty, and cost.
   2. EVA capability maintained for contingency.
   3. Recommended options consider Space Station manpower resources.
   4. Repeatability and frequency of operations fully considered.

CRITERIA \ OPTION		TELEOPERATION WITH EVA	TELEOPERATION ONLY	TELEOPERATION WITH AUTOMATED LATCHES
SUPPORT EQUIPMENT REQUIREMENTS		2 RMS - 1 crew support adapter - 1 grasping adapter EVA support equipment	2 RMS - 1 servicing tool adapter - 1 grasping adapter	1 RMS - 1 grasping adapter
VEHICLE DESIGN REQUIREMENTS		OTV modular design EVA compatible disconnect	OTV modular design EVA/teleoperator compatible disconnect	OTV modular design Automated disconnect
TASK DURATION		18:10	12:50	7:15
MANHOURS	EVA	24:50	---	---
	TOTAL	53:30	20:20	13:45
MANHOUR COST(NMM)		49.5M	7.5M	2.7M
△ VEHICLE WEIGHT PER MISSION		Baseline	Same	+100lb/engine
REQUIRE TECHNICAL DEVELOPMENT		No	Minimal	Yes
ACCESSIBILITY REQUIREMENT		Aerobrake: remove Crew: 4 ft x 5 ft x 6.5 ft RMS : nossle area	Aerobrake: remove Crew: none RMS : 28 in. dia for RMS & tool, nozzle area	Aerobrake: not removed Crew: none RMS : nozzle area
VEHICLE COMPLEXITY		Baseline	Same	Increased - Hardware - Software
VEHICLE RELIABILITY		Baseline	Same	Decrease
COST (REV 8 NMM)		130M	53M	556M

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Table 4-10. Remove and Replace Engine Trade Comparison

Following avionics designs chosen

- Avionics boxes (100 lb. avg. weight) similar to Multi-Mission Spacecraft using bolted or latched interface with core structure
- Removable modular avionics core structure to provide capability for reconfiguring entire system

Standardized payload adapter interface was chosen to provide capability for switching from single to multiple payloads

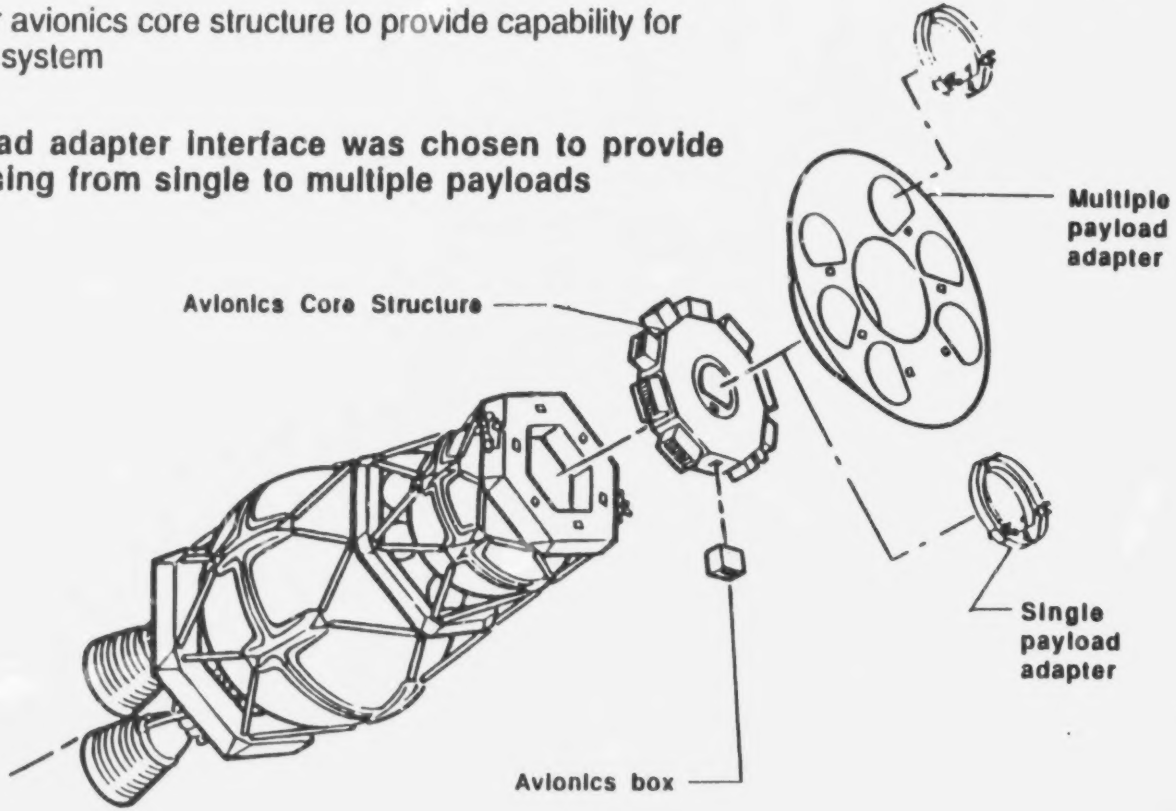

Figure 4-13. Avionics/Payload Removal Replacement

CRITERIA \ OPTION		TELEOPERATION WITH EVA	TELEOPERATION ONLY	TELEOPERATION WITH AUTOMATED LATCHES
SUPPORT EQUIPMENT REQUIREMENTS		2 RMS - 1 crew support adapter - 1 grasping adapter EVA support equipment	2 RMS - 1 servicing tool adapter - 1 grasping adapter	1 RMS - 1 grasping adapter
VEHICLE DESIGN REQUIREMENTS		OTV modular design EVA compatible disconnect	OTV modular design EVA/teleoperator compatible disconnect	OTV modular design Automated disconnect
TASK DURATION		5:50	4:00	3:15
MANHOURS	EVA	4:50	---	---
	TOTAL	15:40	4:00	3:15
MANHOUR COST(NMM)		24.7M	3.3M	2.6M
△ VEHICLE WEIGHT PER MISSION		Baseline	Same	+ 20 lb/unit
REQUIRE TECHNICAL DEVELOPMENT		No	Minimal	Yes
ACCESSIBILITY REQUIREMENT		Crew: 4 ft x 5 ft x 6.5 ft RMS :---	Crew: none RMS : 28 in. dia for RMS & tool	Crew: none RMS : 28 in. dia for RMS & tool
VEHICLE COMPLEXITY		Baseline	Same	Increased - Hardware - Software
VEHICLE RELIABILITY		Baseline	Same	Decrease
COST (REV.8 NMM)		88M	34M	566M

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Table 4-11. Remove and Replace Avionics/Fuel Cell Trade Comparison

CRITERIA / OPTION		TELEOPERATION WITH EVA	TELEOPERATION ONLY	TELEOPERATION WITH AUTOMATED LATCHES
SUPPORT EQUIPMENT REQUIREMENTS		2 RMS - 1 crew support adapter - 1 grasping adapter EVA support equipment	RMS - 1 servicing tool adapter - 1 grasping adapter	1 RMS - 1 grasping adapter
VEHICLE DESIGN REQUIREMENTS		OTV modular design EVA compatible disconnect	OTV modular design EVA/teleoperator compatible disconnect	OTV modular design Automated disconnect
TASK DURATION		3:55	2:25	2:15
MANHOURS	EVA	4:50	---	---
	TOTAL	11:15	2:25	2:15
MANHOUR COST(NMM)		20.2M	1.7M	1.7M
△ VEHICLE WEIGHT PER MISSION		Baseline	Same	+ 20 lb/unit
REQUIRE TECHNICAL DEVELOPMENT		No	Minimal	Yes
ACCESSIBILITY REQUIREMENT		Crew: 4 ft x 5 ft x 6.5 ft RMS :---	Crew: none RMS : 28 in. dia for RMS & tool	Crew: none RMS : 28 in. dia for RMS & tool
VEHICLE COMPLEXITY		Baseline	Same	Increased - Hardware - Software
VEHICLE RELIABILITY		Baseline	Same	Decrease
COST (REV0 NMM)		67M	18M	123M

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Table 4-12. Remove and Replace RCS Thruster Trade Comparison

OPTION / CRITERIA		TELEOPERATION WITH EVA	TELEOPERATION ONLY	TELEOPERATION WITH AUTOMATED LATCHES
SUPPORT EQUIPMENT REQUIREMENTS		2 RMS - 1 crew support adapter - 1 grasping adapter EVA support equipment	2 RMS - 1 servicing tool adapter - 1 grasping adapter	1 RMS - 1 grasping adapter
VEHICLE DESIGN REQUIREMENTS		OTV modular design EVA compatible disconnect	OTV modular design EVA/teleopator compatible disconnect	OTV modular design Automated disconnect
TASK DURATION		10:00	7:35	3:20
MANHOURS	EVA	13:50	---	---
	TOTAL	29:35	7:35	3:20
MANHOUR COST(NMM)		18.5M	1.8M	0.8M
△ VEHICLE WEIGHT PER MISSION		Baseline	Same	+ 20 lb/tank
REQUIRE TECHNICAL DEVELOPMENT		No	Minimal	Yes
ACCESSIBILITY REQUIREMENT		Crew: 4 ft x 5 ft x 6.5 ft RMS : ---	Crew: none RMS : 28 in. dia for RMS & tool	Crew: none RMS : open access exists
VEHICLE COMPLEXITY		Baseline	Same	Increased - Hardware - Software
VEHICLE RELIABILITY		Baseline	Same	Decrease
COST (REV 8 NMM)		56M	19M	223M

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Table 4-13. Remove and Replace Propellant Tank Trade Comparison

We have determined through trades that the most desirable way to perform the operations shown is by teleoperation. EVA capability is required to replace the thermal protection system on the aerobrake and can be used on a contingency basis for all the operations shown.

The following table delineates the types and numbers of people required on the ground to support the space crew in real time during the turnaround operations.

DISCIPLINE	NO OF SUPPORT CREW
Structures Engineer	2
Thermal Engineer	2
Propulsion Engineer	2
Avionics Engineer	4
Mission Planning	3
Mission Operations Support	6
Payload Interface Specialist	2
Maintenance Facility Specialist	2
Total Ground Support Crew	23

These people are the same types of engineers that are used to support the ground processing of an OTV. Their support manhours are counted as a part of the turnaround operation.

4.6 MANPOWER/TIMELINES

4.6.1 INITIAL DELIVERY. The timeline for the initial delivery and assembly of the OTV is presented in Figure 4-14. The OTV can be delivered into space in two shuttle flights. Two RMS are used for deployment and attachment of the aerobrake and installation of the RCS thrusters. One RMS will require MST attachments to connect aerobrake struts, RCS thrusters, and fluid/electrical interfaces. EVA is not required for these operations. The OTV off-load and assembly operation requires a total of 74 space manhours and 849 ground manhours over 5 days.

4.6.2 TURNAROUND. Table 4-15 shows the SBOTV space operations manhour requirements.

4.6.3 NORMAL TURNAROUND. Figure 4-15 gives the time line for a normal turnaround of an SBOTV that is launched with an unmanned payload and returns without a payload. A normal turnaround is one where the vehicle returns to the Space Station from a good flight without faults and does not require periodic maintenance.

The rendezvous and berthing operations begin when the OTV is within 1,000 feet of the Space Station and ends when residual propellant has been offloaded and the OTV is secure in the hangar.

PREDICTED TASK REQUIREMENTS	TELEOPERATIONS WITH EVA		TELEOPERATIONS WITH EVA		TELEOPERATIONS WITH AUTO DISCONN	
	MANHOURS		MANHOURS		MANHOURS	
	TOTAL	EVA	TOTAL	EVA	TOTAL	EVA
250 NORMAL TURNAROUNDS	12229	--	12229	--	12229	--
19 ENGINES R/R (BOTH ENGINES)	1016	472	386	--	261	--
33 TANK STAGE RECONFIGURATIONS	424	72	129	--	115	--
48 AEROBRAKE TPS R/R	2622	1242	(2622)	(1242)	(2622)	(1242)
12 PROPELLANT TANK R/R	346	166	91	--	40	--
- REACTION CONTROL SYSTEM -						
35 RCS THRUSTERS R/R	418	184	90	--	(90)	--
12 RCS N2H4 TANK R/R	537	234	130	--	(130)	--
17 FUEL CELL R/R	264	82	68	--	56	--
24 AVIONICS R/R	330	88	88	--	80	--
TOTAL MANHOURS	16189	2540	15823	1242	15613	1242
AVERAGE MANHOURS PER MISSION	73	10	63	5	62	5
PERCENT EVA		14.0%		7.8%		8.0%
AVERAGE MANHOURS GROUND	785		763		747	

7/15

Table 4-14. SBOTV Turnaround Comparisons

Scheduled maintenance includes helium bottle charge, fuel cell water removal, engine checkout, vehicle visual inspection, system tests, and data analysis.

Payload integration includes payload mating, system checkout, and propellant loading. The time required for payload checkout has not been included in the timeline, since it will vary depending on the payload.

Prelaunch includes all checkout and final preparations for launch.

Launch operations consist of deploying the OTV and payload to a point 1,000 feet from the Space Station where control is turned over to mission operations.

Shown on the chart are the manhours required on the Space Station and for the support personnel on the ground.

4.6.4 OTV UTILIZED AT THE STATION. Table 4-16 shows the mission time and the projected turnaround time required for an OTV at the Space Station. Two mission years were selected. The first year is 1998 with 14 missions. They are all unmanned delivery missions so the average mission time should be approximately 5 days. The average OTV turnaround time from the previous chart should be not more than 10 days. Worst-case configuration and maintenance tasks were assumed for the turnaround analysis.

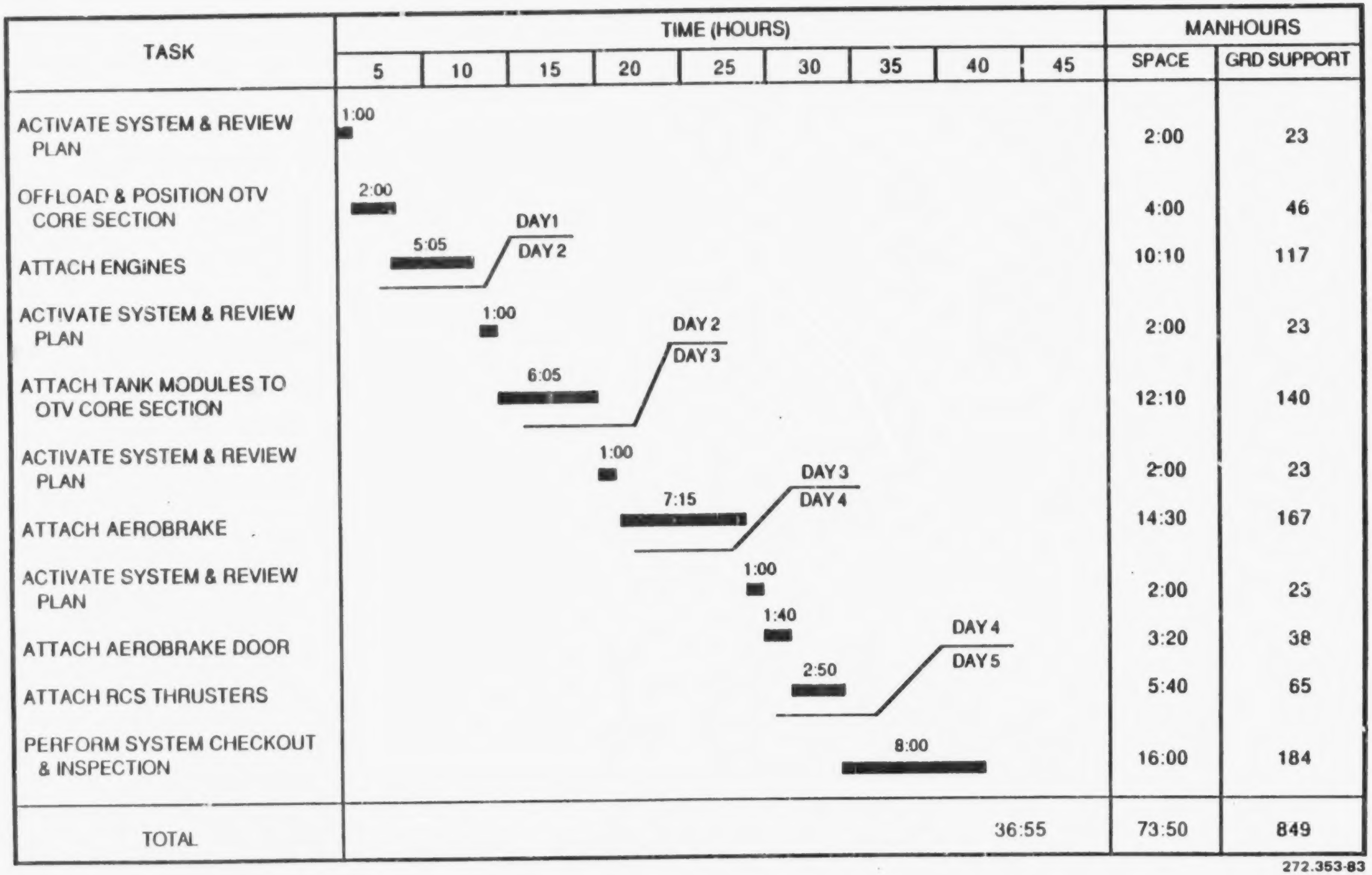
The second year is 2010. The manned missions could increase the average mission time to approximately 8 days. By that time the OTV should be able to be turned around in an average of 8 days.

The conclusions reached from this data are that, with no scheduling conflicts, one OTV will satisfy the mission model turnaround and OTV accommodations are not affected by turnaround requirements.

4.7 COMPARISON OF SPACE/GROUND PROCESSING

We cannot directly compare the manhours for turning an OTV around on the ground with the manhours to turn around an OTV in space because of the different functional tasks that need to be performed in each place. Figure 4-16 is the functional flow chart for the ground processing of a cargo bay OTV. We marked the major functions on this chart that are equivalent to the ones that are performed at the Space Station. It can be seen that there are a lot of functions that are performed on the ground that are not required in space, namely moving between facilities, ASE processing, and Shuttle Orbiter interface and mating activities. The following tables will identify the manhours for these equivalent tasks.

Table 4-17 shows the manhours for ground processing for major tasks equivalent to major tasks performed on the OTV at the Space Station. These are the tasks identified in the previous figures. It can be seen that there is quite a difference in the manhours for ground processing an OTV on the ground as compared to the tasks needed in space. This is mainly attributed to the required moving between facilities, ASE processing, and Shuttle Orbiter interface and mating activities. This table identifies the major task differences. The following table will modify these numbers further to arrive at a reduced number of equivalent manhours.



TASK	TIME (HOURS)	MANHOURS	
		SPACE	GRD SUPPORT
ACTIVATE SYSTEM & REVIEW PLAN	1:00	2:00	23
OFFLOAD & POSITION OTV CORE SECTION	2:00	4:00	46
ATTACH ENGINES	5:05	10:10	117
ACTIVATE SYSTEM & REVIEW PLAN	1:00	2:00	23
ATTACH TANK MODULES TO OTV CORE SECTION	6:05	12:10	140
ACTIVATE SYSTEM & REVIEW PLAN	1:00	2:00	23
ATTACH AEROBRAKE	7:15	14:30	167
ACTIVATE SYSTEM & REVIEW PLAN	1:00	2:00	23
ATTACH AEROBRAKE DOOR	1:40	3:20	38
ATTACH RCS THRUSTERS	2:50	5:40	65
PERFORM SYSTEM CHECKOUT & INSPECTION	8:00	16:00	184
TOTAL	36:55	73:50	849

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Figure 4-14. Initial SBOTV Delivery and Assembly

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS	
		SPACE	GROUND
5.1	OFFLOAD AND POSITION OTV CORE SECTION	6:00	69:00
5.2	ATTACH ENGINES TO CORE SECTION	10:10	116:55
5.3	ATTACH HYDROGEN TANK MODULES TO CORE	14:10	163:10
5.4	ATTACH RCS SYSTEM	5:40	65:00
5.5	ATTACH AEROBRAKE AND DOOR	21:50	251:05
5.6	PERFORM SYSTEM CHECKOUT AND INSPECTION	16:00	184:00
6.1	RECONFIGURE OTV	1:00	13:25
6.2	PREPARE OTV FOR SPACECRAFT MATING	2:40	38:20
6.3	MATE SPACECRAFT TO OTV	4:30	59:25
6.4	PERFORM OTV/SPACECRAFT CHECKOUT	TBD	TBD
6.5	TRANSFER PROPELLANTS	4:40	103:50
7.1	PERFORM LAUNCH CONFIDENCE TESTS	8:00	92:00
7.2	RELEASE OTV FROM SPACE STATION	2:00	23:00
7.3	MANEUVER OTV TO LAUNCH PROXIMITY	2:30	28:45
7.4	PERFORM LAUNCH COUNTDOWN	0:30	5:45

1-2 (7/15.
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Table 4-15. SBOTV Space Operations Manhour Requirements

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS	
		SPACE	GROUND
9.1	RENDEZVOUS OTV WITH SPACE STATION	4:20	49:50
9.2	BERTH OTV	0:40	7:40
9.3	TRANSFER RESIDUAL PROPELLANT	1:25	28:75
9.4	SECURE OTV	1:10	13:25
10.1	PERFORM FLIGHT DATA ANALYSIS	1:00	11:30
10.2	PERFORM VISUAL INSPECTION OF OTV	2:00	23:00
10.3	PREPARE MAINTENANCE PLAN	1:00	11:30
10.4	PERFORM SERVICING	10:00	115:00
10.5	PERFORM SCHEDULED MAINTENANCE	12:00	100:45
10.6	PERFORM UNSCHEDULED MAINTENANCE	1:50	42:10
10.7	PERFORM SYSTEMS OPERATIONAL TEST	1:30	17:15
	TOTAL MANHOURS INITIAL FLIGHT	102:15	1301:00
	TOTAL MANHOURS TURNAROUND (6.1-10.7)	62:55	762:50

2-2 (7/15)
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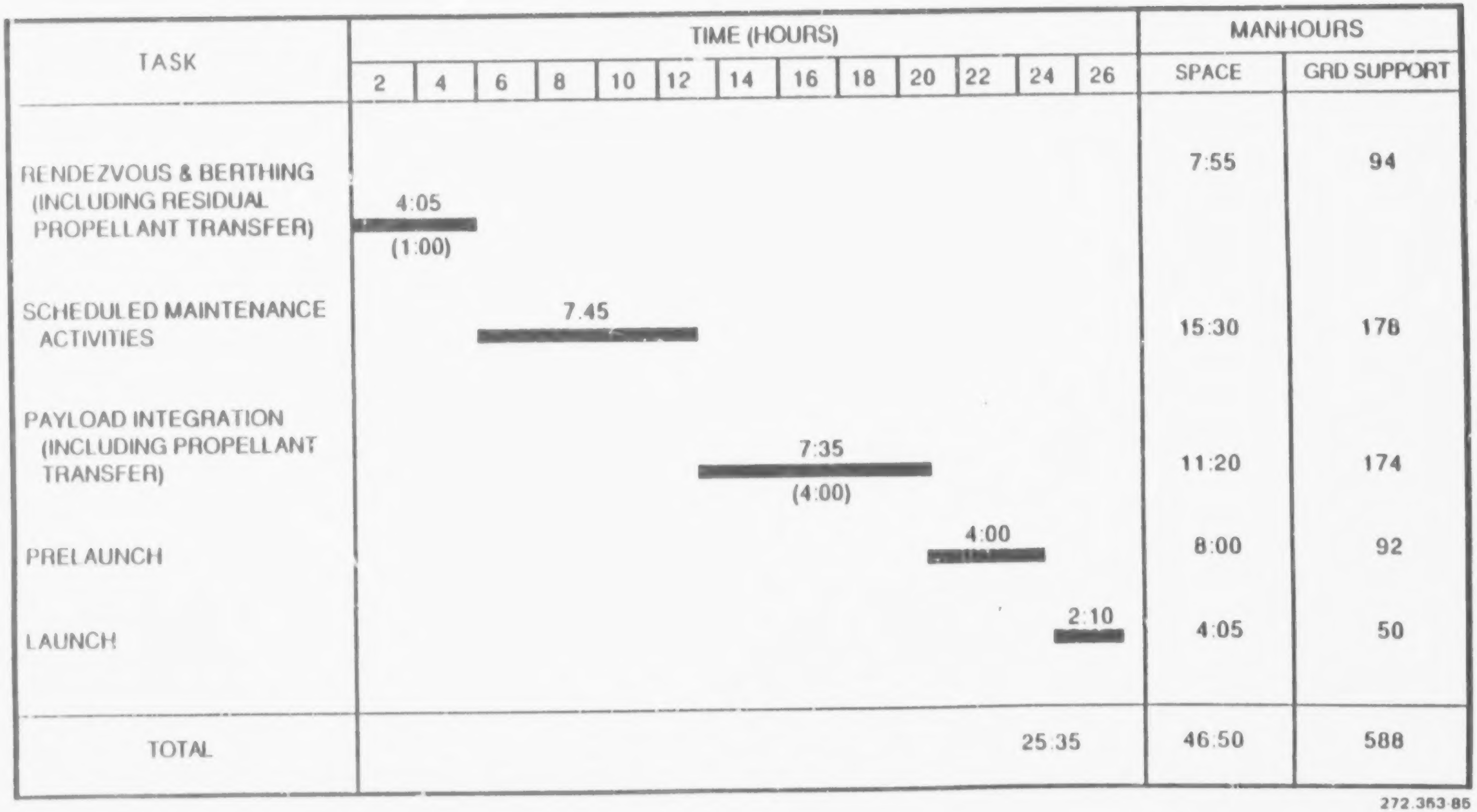
Table 4-15. SBOTV Space Operations Manhour Requirements, Contd



TASK	TIME (HOURS) 2 4 6 8 10 12 14 16 18 20 22 24 26	MANHOURS SPACE	MANHOURS GRD SUPPORT
RENDEZVOUS & BERTHING (INCLUDING RESIDUAL PROPELLANT TRANSFER)	4:05 (1:00)	7:55	94
SCHEDULED MAINTENANCE ACTIVITIES	7.45	15:30	178
PAYLOAD INTEGRATION (INCLUDING PROPELLANT TRANSFER)	7:35 (4:00)	11:20	174
PRELAUNCH	4:00	8:00	92
LAUNCH	2:10	4:05	50
TOTAL	25:35	46:50	588

272.353-85

Figure 4-15. Normal Turnaround Unmanned Payload

Table 4-18 takes the manhours for the major ground processing tasks that are equivalent to tasks performed in space and removes some subtasks that are not applicable to tasks in space to arrive at roughly an equivalent number of manhours for ground processing to match the space processing tasks.

Table 4-19 roughly compares equivalent ground processing and space processing manhour requirements.

More manhours are required to ground process a GBOTV that to space process an SBOTV.

Manpower is a lot cheaper on the ground, so more men can be assigned to the job. In addition, no more than two crewmen will be able to perform hands-on tasks on the SBOTV at the Space Station, whereas many more can perform hands-on tasks on the ground, and also stand around and observe/inspect this work.

4.8. SBOTV TURNAROUND ASSESSMENT

Besides the crew at the Space Station, support people are required on the ground to perform the turnaround operations.

The following summarizes the features of the SBOTV that allows it to be based at the Space Station and turned around in a safe and efficient manner:

a. Vehicle is fully checked on ground with planned assembly at the Space Station.

b. Turnaround operations are optimized by restriction to Level 1 maintenance.

c. Maintainability is a primary vehicle/system design requirement

   1. Accessibility for remote and EVA operations.

   2. Modular construction of SBOTV simplifies and speeds up replacement process.

d. Checkout accomplished with vehicle built-in test capability

   1. Vehicle computer system evaluates and registers fault during mission.

   2. Vehicle status relayed to station via RF datalink or through data base interconnect after berthing.

   3. Interfaces automatically connected during berthing operations.

e. Computer system analyzes and displays vehicle status and presents basic maintenance plan

f. Inspection TV without tear down operation

g. Majority of maintenance tasks are accomplished by teleoperations

h. No Shuttle interface operations required beyond initial delivery

i. Vehicle is not subjected to space-Earth transition environment

j. Vehicle berths at maintenance facility: Does not move between facilities with attendant inspection/retest

REVISION 8 NOMINAL MISSION MODEL	MISSION TIME (DAYS)	TURNAROUND TIME (DAYS)	STORAGE TIME (DAYS)
YEAR 1998 - 14 MISSIONS	70 (AVERAGE 5)	140 (AVERAGE 10)	140*
YEAR 2010 - 21 MISSIONS	168 (AVERAGE 8)	168 (AVERAGE 8)	29*

*Only one OTV at Space Station for nominal time between missions.

Table 4-16. OTV Utilized at Space Station

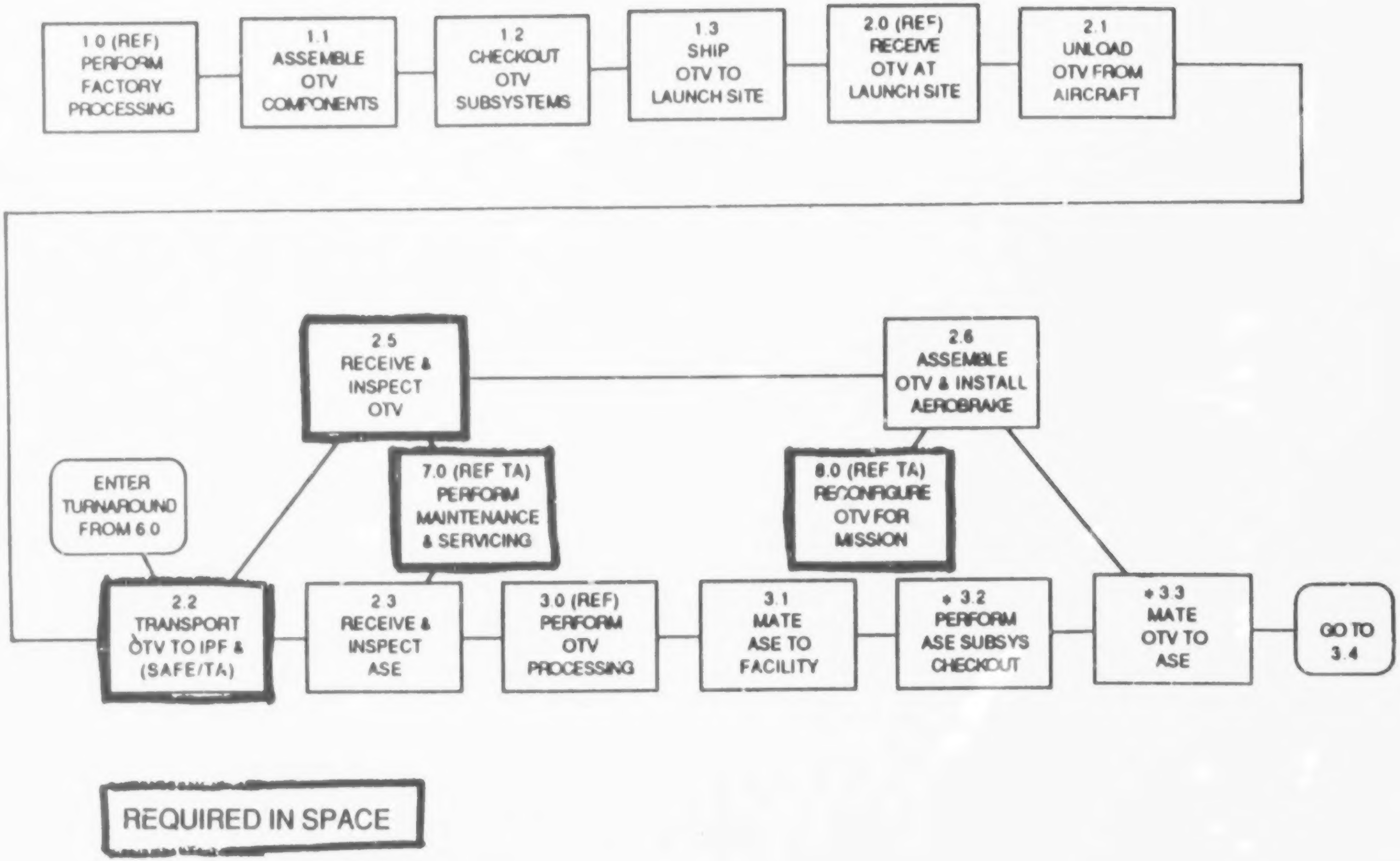

1.0 (REF) PERFORM FACTORY PROCESSING
1.1 ASSEMBLE OTV COMPONENTS
1.2 CHECKOUT OTV SUBSYSTEMS
1.3 SHIP OTV TO LAUNCH SITE
2.0 (REF) RECEIVE OTV AT LAUNCH SITE
2.1 UNLOAD OTV FROM AIRCRAFT
ENTER TURNAROUND FROM 6.0
2.2 TRANSPORT OTV TO IPF & (SAFE/TA)
2.5 RECEIVE & INSPECT OTV
7.0 (REF TA) PERFORM MAINTENANCE & SERVICING
2.3 RECEIVE & INSPECT ASE
3.0 (REF) PERFORM OTV PROCESSING
3.1 MATE ASE TO FACILITY
2.6 ASSEMBLE OTV & INSTALL AEROBRAKE
8.0 (REF TA) RECONFIGURE OTV FOR MISSION
* 3.2 PERFORM ASE SUBSYS CHECKOUT
* 3.3 MATE OTV TO ASE
GO TO 3.4
REQUIRED IN SPACE

Figure 4-16. Equivalent Ground Functional Tasks Required in Space: Cargo Bay OTV by IPF.

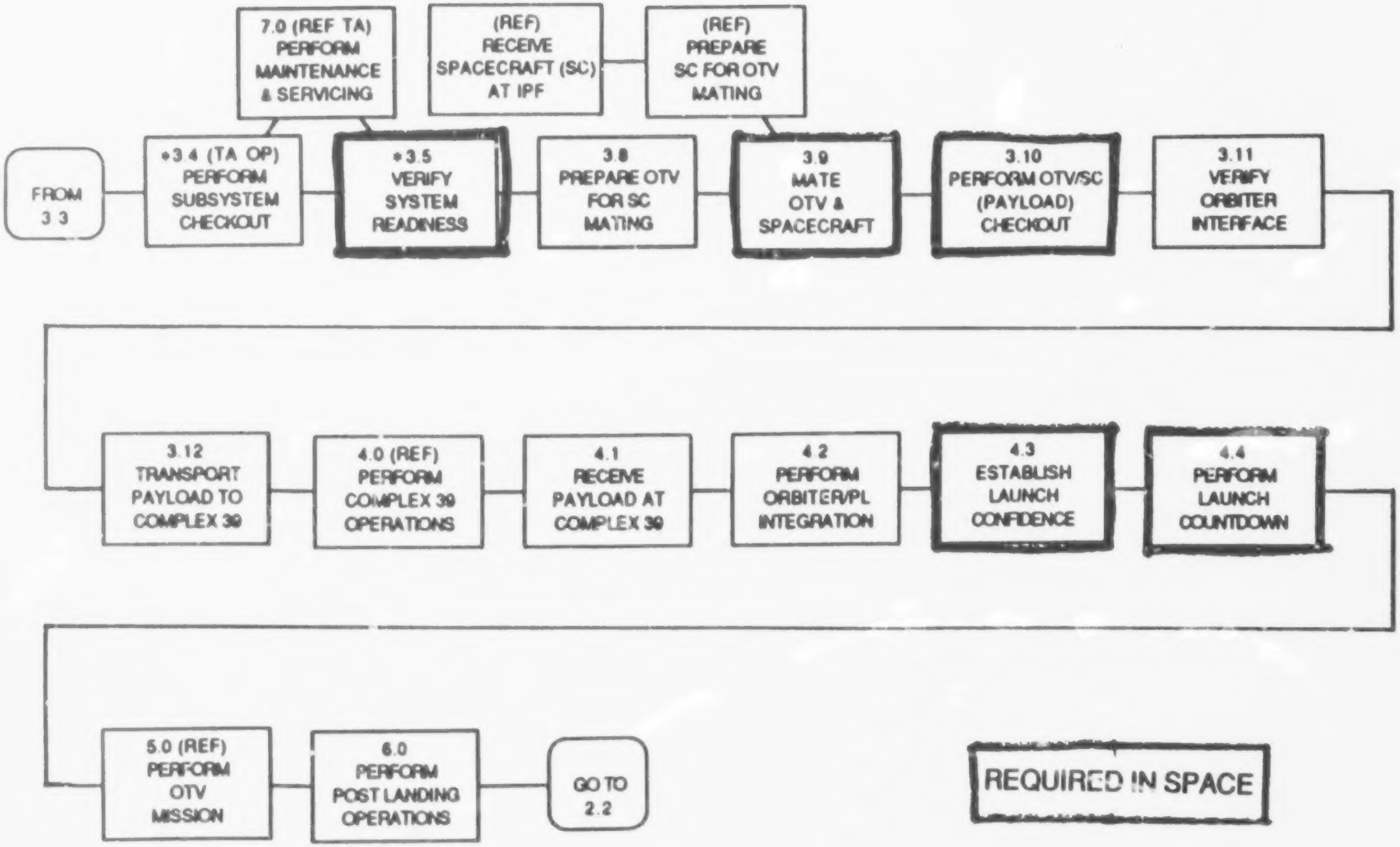

7.0 (REF TA) PERFORM MAINTENANCE & SERVICING
(REF) RECEIVE SPACECRAFT (SC) AT IPF
(REF) PREPARE SC FOR OTV MATING
FROM 3 3
*3.4 (TA OP) PERFORM SUBSYSTEM CHECKOUT
*3.5 VERIFY SYSTEM READINESS
3.8 PREPARE OTV FOR SC MATING
3.9 MATE OTV & SPACECRAFT
3.10 PERFORM OTV/SC (PAYLOAD) CHECKOUT
3.11 VERIFY ORBITER INTERFACE
3.12 TRANSPORT PAYLOAD TO COMPLEX 39
4.0 (REF) PERFORM COMPLEX 39 OPERATIONS
4.1 RECEIVE PAYLOAD AT COMPLEX 39
4.2 PERFORM ORBITER/PL INTEGRATION
4.3 ESTABLISH LAUNCH CONFIDENCE
4.4 PERFORM LAUNCH COUNTDOWN
5.0 (REF) PERFORM OTV MISSION
6.0 PERFORM POST LANDING OPERATIONS
GO TO 2.2
REQUIRED IN SPACE

Figure 4-16. Equivalent Ground Functional Tasks Required in Space: Cargo Bay OTV by IPF, Contd

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS	
		TURNAROUND	
		INTEGRATED FAC. FULLY AUTOMATED	EQUIVALENT SPACE TASKS
2.1	UNLOAD OTV FROM AIRCRAFT	--	--
2.2	TRANSPORT OTV TO HANGAR J/IPF	22	22
2.3	RECEIVE AND INSPECT ASE	280	--
2.4	TRANSPORT ASE TO OTVPF	--	--
2.5	OTV RECEIVE AND INSPECT	488	488
2.6	ASSEMBLE OTV AND INSTALL BALLUTE	208	--
2.7	TRANSPORT OTV TO OTVPF	--	--
3.1	MATE ASE TO FACILITY	48	--
3.2	PERFORM ASE SUBSYSTEM CHECKOUT	456	--
3.3	MATE OTV TO ASE	840	--
3.4	PERFORM SUBSYSTEM CHECKOUT	1376	--
3.5	VERIFY SYSTEM READINESS	720	720
3.6	TRANSPORT OTV TO VPF	--	--
3.7	RECEIVE OTV AT VPF	--	--

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Table 4-17. Equivalent Ground Tasks Required in Space: Cargo Bay OTV

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS	
		TURNAROUND	
		INTEGRATED FAC. FULLY AUTOMATED	EQUIVALENT SPACE TASKS
3.8	PREPARE OTV FOR SPACECRAFT MATING	--	--
3.9	MATE OTV AND SPACECRAFT	104	104
3.10	PERFORM OTV AND SPACECRAFT CHECKOUT	154	154
3.11	VERIFY ORBITER INTERFACE	96	--
3.12	TRANSPORT PAYLOAD TO CX39	418	--
4.1	RECEIVE PAYLOAD AT CX39	176	--
4.2	PERFORM ORBITER/PAYLOAD INTEGRATION	708	--
4.3	ESTABLISH LAUNCH CONFIDENCE	624	624
4.4	PERFORM LAUNCH COUNTDOWN	360	360
5.0	PERFORM OTV MISSION	--	--
6.0	PERFORM POST MISSION OPS	384	--
7.0	PERFORM MAINTENANCE & SERVICING	40	40
8.0	RECONFIGURE OTV FOR MISSION	80	80
	TOTAL MANHOURS	7582	2592

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Table 4-17. Equivalent Ground Tasks Required in Space: Cargo Bay OTV, Contd

OTV TASK NUMBER	GROUND MHRS	RATIONAL FOR GREATER GROUND HOURS →	EQUIVALENT SPACE MHRS
2.2	22		22
2.5	488	• ORBITER INTERFACE/HANDLING • UPLOADS/DOWNLOADS • DISASSEMBLE VEHICLE	232
3.5	720	• ORBITER INTERFACE/HANDLING • UPLOADS/DOWNLOADS • DISASSEMBLE VEHICLE	304
3.9	104	• GRAVITY/CRANES	104(ZERO G TELEOPERATIONS)
3.10	154	• MANUAL HARNESS CHECKS	122
4.3	624	• TEST BECAUSE OF MOVE TO CX36 • PREP FACILITIES FOR TEST	408
4.4	360	• TECH/MECHS/INSPECTORS	168
7.0	40		40
8.0	80		80
TOTAL	2592		1480

Table 4-18. Manpower Comparison of Equivalent Ground and Space Tasks

EQUIVALENT BASIS

ITEM	MANHOURS
ALL GROUND-BASED TURNAROUND TASKS-GBOTV	7582
EQUIVALENT GROUND-BASED TURNAROUND TASKS TO SPACE-BASED TURNAROUND TASKS AFTER ELIMINATION OF TASKS ON THE GROUND THAT ARE NOT REQUIRED IN SPACE	1480
**SPACE-BASED TURNAROUND TASKS - SBOTV	
IN SPACE	63
ON GROUND	763

** NO MORE THAN TWO CREWMEN CAN PERFORM HANDS-ON TASKS ON THE SBOTV, AND TELEOPERATIONS REDUCES MANPOWER REQUIREMENTS

Table 4-19. Comparison of Ground-Based and Space-Based Turnaround Tasks

k. Operations philosophy assumes vehicle is operational after good flight with aid of instrumental and computer assessment (more instrumentation than GBOTV)

l. Vehicle does not need to be dismantled after each mission, which minimizes damage due to maintenance operations

m. Fewer hands-on manual operations: Less likelihood of mistakes

Figure 4-17 shows how the ground processing analysis progressed from the Shuttle Centaur data through the cargo bay OTV alternatives to the other OTV concepts and then on to the space processing.

GDSS used the manhours expended on processing the first Shuttle Centaur through ELS up to launch as our starting point. We modified those numbers to eliminate nonprocessing-related tasks to come up with the 39,000-manhour number. We modified that number to project what we thought it would take to process a Shuttle Centaur on a nominal schedule of several a year.

From this data, we investigated what tasks it would take to process and OTV. We looked at Shuttle-Centaur-type facilities and tasks to start with and then projected what it would take for other facilities and types of tasks.

After we analyzed the cargo bay OTV alternative processing tasks, we applied this knowledge to come up with manpower and times for the other OTV concepts.

For space processing, we used the Shuttle Centaur and OTV ground processing data as a data base. We modified the ground processing data to eliminate tasks that were not needed at the Space Station. We then analyzed these tasks to come up with approaches and manpower to perform them in a space environment. The recommended are shown in the figure.

4.9 RECOMMENDED TASK DESCRIPTIONS

The task description sheets (see Table 4-20 as an example) contain data peculiar to each Level 2 task of the OTV turnaround. The task identification code and descriptor are the same as those used throughout the study. The purpose and a narrative description of the task are presented along with the resource requirements, task duration and frequency. The resource requirements include the crew size and manhour requirements for the task in addition to the accommodations required to perform the task. A complete set of the task description sheets has been given to the MSFC COR Donald Saxton.

4.10 PROPELLANT DELIVERY OPERATIONS

The functional flow diagram (see Figure 4-18) shows the tasks required to deliver propellants to the Space Station and subsequent transfer to the long-term cryogenic storage facility (LTCSF). These tasks begin after the propellant resupply tanker is placed in a holding orbit by an expendable launch vehicle. The OMV retrieves the tanker and maneuvers it to the Space Station. The propellant is transferred from the tanker to the storage facility, then the tanker is deorbited.

The flow also includes the tasks required for OMV operation to perform its retrieval and delivery operations.

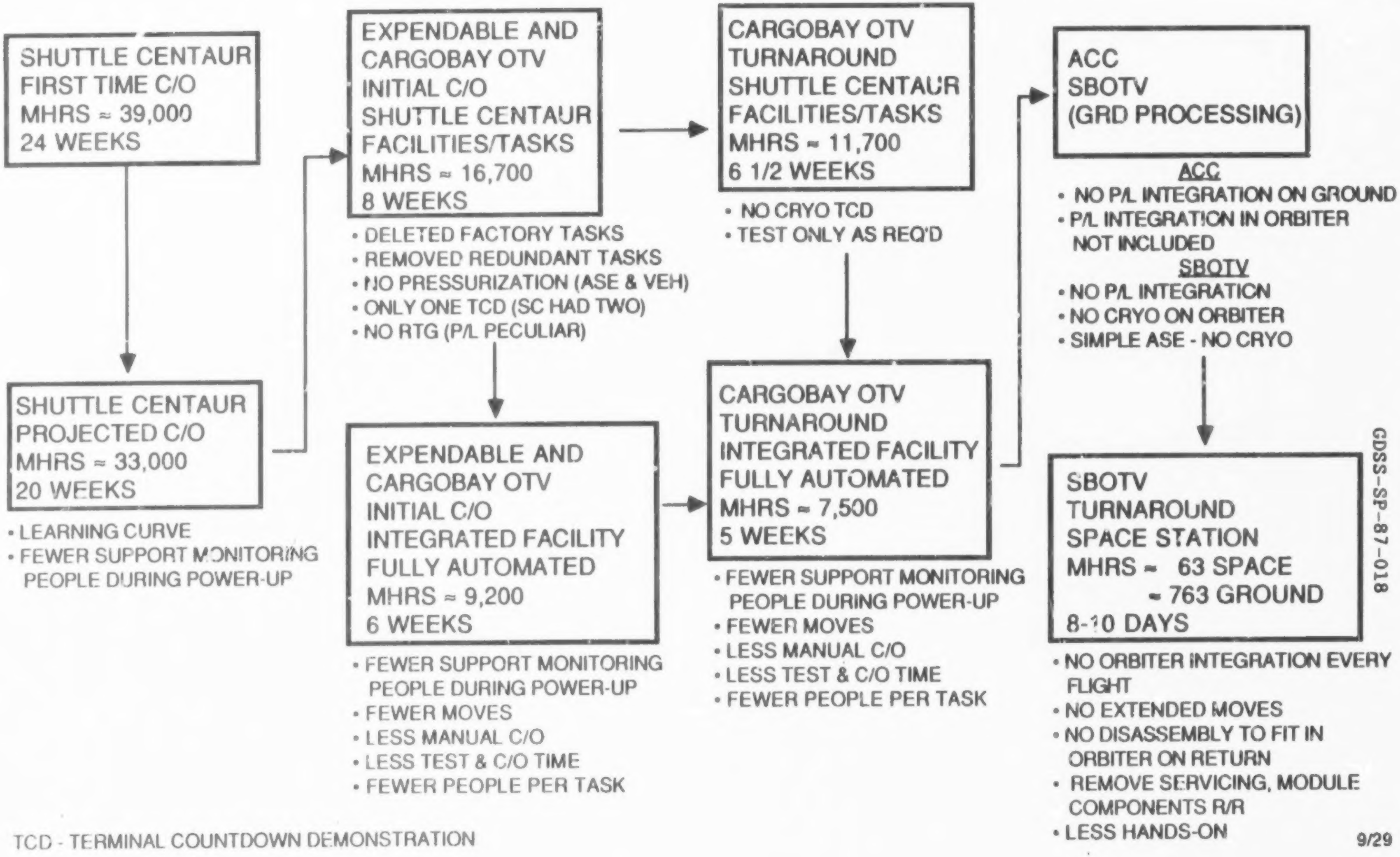

Figure 4-17. Ground Processing Progression to Space Processing

TASK-IDENT	DESCRIPTOR
5.3	ATTACH HYDROGEN TANK MODULES TO CORE SECTION

NEXT HIGHER TASK
5.0 PERFORM INITIAL DELIVERY AND ASSEMBLY

PURPOSE
TO ASSEMBLE THE OTV UPON INITIAL DELIVERY TO THE SPACE STATION.

TASK DESCRIPTION
TRANSFER OTV HYDROGEN TANK MODULES FROM THE SHUTTLE CARGO BAY TO THE OTV HANGAR. THE TANKS WILL THEN BE ATTACHED TO THE CORE SECTION.

TASK DURATION	TASK FREQUENCY
7 HOURS 3 MINUTES	ONCE EVERY 40 MISSIONS

RESOURCE REQUIREMENTS

CREW

	CREW SIZE	MANHOURS
IVA	2	14:[illegible]
EVA	0	
GROUND	23	163:[illegible]
	----	----
TOTAL	25	177:[illegible]

ACCOMMODATIONS
STATION RMS AND CONTROLS
MST FOR HANGAR RMS
COMPUTER SYSTEM
GRD SPRT DATALINK (COMM)
HANGAR RMS AND CONTROLS
CCTV SYSTEM
FACILITY CONTROLS

SPARES

OTHER VEHICLE SYSTEMS EFFECTED

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Table 4-20. Task Description Sheet: Space Operations SBOTV

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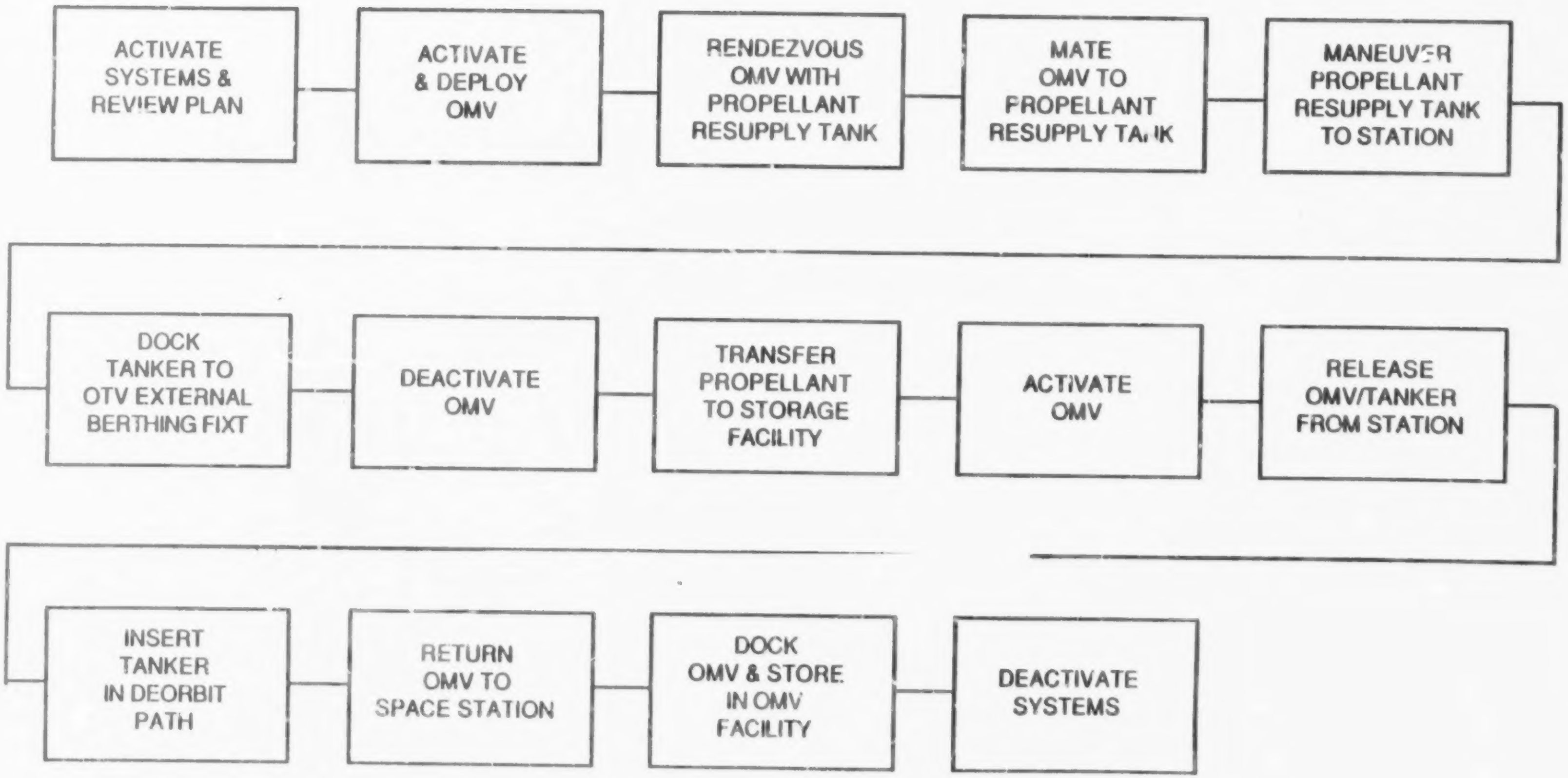
ACTIVATE SYSTEMS & REVIEW PLAN
ACTIVATE & DEPLOY OMV
RENDEZVOUS OMV WITH PROPELLANT RESUPPLY TANK
MATE OMV TO PROPELLANT RESUPPLY TANK
MANEUVER PROPELLANT RESUPPLY TANK TO STATION
DOCK TANKER TO OTV EXTERNAL BERTHING FIXT
DEACTIVATE OMV
TRANSFER PROPELLANT TO STORAGE FACILITY
ACTIVATE OMV
RELEASE OMV/TANKER FROM STATION
INSERT TANKER IN DEORBIT PATH
RETURN OMV TO SPACE STATION
DOCK OMV & STORE IN OMV FACILITY
DEACTIVATE SYSTEMS

Figure 4-18. Propellant Delivery Operations Flow

The propellant delivery crew requirements (see Table 4-21) include task duration times and manhours committments by the Space Station crew during the propellant delivery operation. The propellant transfer task is the only propellant delivery task not requiring two crew members. This task is automated and only requires one person to monitor the operation.

4.11 OTV SUPPORT EQUIPMENT MAINTENANCE

4.11.1 MAINTENANCE REQUIREMENTS. The maintenance requirements shown in Table 4-22 are the corrective and preventive maintenance for the equipment required to support OTV operations in space. This includes the task time, manhour requirements, task frequency, type of maintenance, and implementation methods.

The maintenance requirements shown in Table 4-23 are the corrective and preventive maintenance for one storage tank system. This includes the quantity of the ORUs, task time, manhour requirements, and frequency of remove and replace. The same support equipment will be used on both tank systems.

4.11.2 SUPPORT EQUIPMENT MANHOURS. Table 4-24 presents the manhour requirements for OTV support equipment maintenance.

Table 4-25 shows the crew requirements for maintenance of the LTCSF. This includes the two storage tank systems. The average task time is 48 hours or 6 days per year.

Table 4-26 summarizes the average yearly manhour requirements in space for operation and maintenance of the OTV and its support equipment. This includes OTV turnaround, propellant resupply and maintenance of both the support equipment and LTCSF. The number of IVA and EVA manhours required for each of these operations are also shown.

Table 4-27 summarizes the time that each crew size is required to perform the various OTV operations and maintenance tasks for the SBOTV.

One and two member crews perform their tasks in an IVA mode. The three member crew is composed of one IVA member in support of two EVA members task implementation. The two member crew is used during payload mating, launch and retrieval operations while one-and three-member crews are used for maintenance and servicing tasks.

4.12 CONCLUSIONS

The following are conclusions arrived at during the analysis just completed on space processing:

a. Use teleoperations for SBOTV turnaround tasks except for aerobrake thermal protection system (EVA)

b. Nominal turnaround for SBOTV 61 Manhours in space
754 Manhours on ground
7 Days + Mission

c. SBOTV can be based at the Space Station and turned around in a safe and cost-effective manner

TASK	TASK TIME	MANHOURS
ACTIVATE SYSTEM & REVIEW PLAN	1:00	2:00
ACTIVATE & DEPLOY OMV	1:00	2:00
RENDEZVOUS OMV WITH TANKER	1:30	3:00
MATE OMV TO TANKER	0:40	1:20
MANEUVER TANKER TO SS	1:45	3:30
DOCK TANKER TO OTV BERTHING FXTR	1:10	2:20
DEACTIVATE OMV	0:10	0:20
TRANSFER PROPELLANT TO LTCSF	8:30	8:40
ACTIVATE OMV	0:15	0:30
RELEASE OMV TANKER FROM SS	0:35	1:10
INSERT TANKER IN DE-ORBIT PATH	1:00	2:00
RETURN OMV TO SS	1:30	3:00
DOCK OMV AND STORE IN OMV FACILITY	1:15	2:30
DEACTIVATE SYSTEM	0:15	0:30
TOTAL	20:35	32:50

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Table 4-21. Propellant Delivery Crew Requirements

OTV SUPPORT EQUIPMENT	MAINTENANCE FUNCTION	SCHED	UNSCHED	EVA	TELEOP	TASK DURATION	TASK FREQUENCY	EQUIPMENT REQUIREMENTS	MANHOURS	
									IVA	EVA
SERVICING MAIN TRUSS SUPPORT STRUCTURE	• VISUAL INSPECTION	X			X	4 HRS	ONCE EVERY 6 MO	RMS WITH CCTV	4:00	-
	• REPLACE INDIVIDUAL TRUSS STRUTS		X	X		5 HRS/ TRUSS	AS REQUIRED	EVA SUPPORT EQUIP. RMS WITH EVA CREW SUPPORT ADAPTER	10:00	5:00
HANGAR INTERNAL BERTHING FIXTURE (ROTARY)	• VISUAL INSPECTION	X			X	5 MIN	ONCE PER MISSION	RMS WITH CCTV	0:05	-
	• REPLACE FIXTURE		X	X		6:45 HRS	WHEN REQUIRED	EVA SUPPORT EQUIP. RMS WITH EVA CREW SUPPORT ADAPTER	11:45	8:30
ELECTRICAL INTERCONNECTS BETWEEN INTERNAL BERTHING I/F, OTV CONTROL EQUIPMENT AND POWER SOURCE	• VISUAL INSPECTION	X			X	INCLUDED W/INTERNAL BERTHING FIXTURES	ONCE PER MISSION	RMS WITH CCTV	-	-
OTV EXTERNAL BERTHING FIXTURE	• VISUAL INSPECTION	X			X	5 MIN	TWICE PER MISSION	RMS WITH CCTV	0:05	-
	• REPLACE FIXTURE		X	X		6 HRS	WHEN REQUIRED	EVA SUPPORT EQUIP RMS WITH EVA CREW SUPPORT ADAPTER	11:00	7:00
ELECTRICAL CONNECTION BETWEEN EXTERNAL BERTHING I/F, OTV CONTROL EQUIPMENT AND POWER SOURCE	• VISUAL INSPECTION	X			X	INCLUDED W/EXTERNAL BERTHING FIXTURE	TWICE PER MISSION	RMS WITH CCTV	-	-
SUPPORT STRUCTURES FOR HANGAR EQUIPMENT	• VISUAL INSPECTION	X			X	INCLUDE W/MAIN TRUSS SUPPORT	ONCE EVERY 6 MO	RMS WITH CCTV	-	-
	• REPLACE SUPPORT STRUCTURE		X	X		5 HRS	AS REQUIRED	EVA SUPPORT EQUIP RMS WITH EVA CREW SUPPORT ADAPTER	10:00	5:00

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Table 4-22. OTV Support Equipment Maintenance Requirements

OTV SUPPORT EQUIPMENT	MAINTENANCE FUNCTION	SCHED	UNSCHED	EVA	TELEOP	TASK DURATION	TASK FREQUENCY	EQUIPMENT REQUIREMENTS	MANHOURS	
									IVA	EVA
CCTV CAMERAS	• READJUST		X		X	4 HRS ALL CAMERAS	AVG ONCE/YR	RMS WITH GRASPING ADAPTER	4:00	-
	• REMOVE & REPLACE		X	X		5 HRS	AS REQUIRED	EVA SUPPORT EQUIPMENT	10:00	5:00
LIGHTING	• READJUST		X		X	10 MIN	AS REQUIRED	RMS WITH GRASPING ADAPTER	0:10	-
	• LIGHT BULBS		X	X		7 (10 MIN EA)	EVERY 500 HR	EVA SUPPORT EQUIP RMS WITH CREW SUPPORT ADAPTER	12:00	9:00
	• REMOVE & REPLACE LIGHT FIXTURE		X	X		4 HRS	AS REQUIRED	EVA SUPPORT EQUIP RMS WITH CREW SUPPORT ADAPTER	9:00	3:00
LEAK DETECTION	• CHECKOUT	X			X	30 MIN	ONCE/YR	RMS	0:30	-
	• REMOVE & REPLACE		X	X		5:30 HRS	AS REQUIRED	EVA SUPPORT EQUIP RMS WITH CREW SUPPORT ADAPTER	10:30	5:00
COMMUNICATION LINES	• REMOVE & REPLACE		X	X		8 HRS	AS REQUIRED	EVA SUPPORT EQUIP RMS WITH CREW SUPPORT ADAPTER	13:00	11:00
2 HANGAR RMS (LIGHT ETU SEE ABOVE)	• R/R MOTORS		X	X		8 HRS	AS REQUIRED	•	13:00	11:00
	• POSITION, VELOCITY & ACCELERATOR INDICATOR CHECKOUT	X			X	5 MIN	BEFORE EACH USE	•	0:05	-
	• R/R JOINTS		X	X		10 HRS	AS REQUIRED	•	15:50	16:00
EVA ADAPTER - WORK STATION	• R/R WORK STATION		X	X		OFF LOAD ONLY	RETURN TO GROUND	RMS	-	-
MST ADAPTER & OTHER TOOLS	• THIS TOOL WOULD BE REPLACED					N/A	NO REPAIR ANTICIPATED	RMS	-	-

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Table 4-22. OTV Support Equipment Maintenance Requirements, Contd

OTV SUPPORT EQUIPMENT	MAINTENANCE FUNCTION	SCHED	UNSCHED	EVA	TELEOP	TASK DURATION	TASK FREQUENCY	EQUIPMENT REQUIREMENTS	MANHOURS	
									IVA	EVA
PROTECTIVE COVERING (MICROMETEROID & SPACE DEBRIS	• VISUALLY INSPECT	X			X	2:30 HRS	2 PER YR	RMS WITH CCTV	2:30	-
	• R/R PC SECTIONS		X	X		14 HRS	AS REQUIRED	EVA SUPPORT EQUIP. RMS WITH EVA CREW SUPPORT ADAPTER 2ND RMS	24:00	18:00
HANGAR OPENING SCREEN	• VISUALLY INSPECT	X			X	30 MIN	2 PER YR	RMS WITH CCTV	0:30	-
	• R/R SCREEN		X	X		14 HRS		EVA SUPPORT EQUIP. RMS WITH EVA CREW SUPPORT ADAPTER	26:00	18:00
	• R/R DRIVE MOTOR		X	X		6:20 HRS		EVA SUPPORT EQUIP. RMS WITH EVA CREW SUPPORT ADAPTER	12:00	7:40
SPARES HOLDING FIXTURE	• VISUALLY INSPECT		X		X		ONLY WHEN REMOVING/ STORING	RMS WITH CCTV SPARES	-	-
	• R/R FIXTURES		X	X		5 HRS		EVA SUPPORT EQUIP. RMS WITH CREW SUPPORT ADAPTER	10:00	5:00
CONTROL PANEL	• R/R		X	IVA		1:30 HRS	AS REQUIRED			
CHECKOUT EQUIPMENT	• R/R SWITCHES		X							
	• WIRE CONNECTIONS		X							

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Table 4-22. OTV Support Equipment Maintenance Requirements, Contd

ORU	QUANTITY PER TANK SYSTEM	TASK TIME (HR) (EA)	PRIMARY MAINTENANCE OPERATION	MANHOURS		FREQUENCY PER TANK SET	SUPPORT EQUIPMENT
				IVA (EA)	EVA (EA)		
LH2 & LO2 RELIEF & VENT VALVES	4	7	EVA	12:15	9:00	NO FAILURE ANTICIPATED	EVA SUPPORT EQUIPMENT. RMS WITH EVA CREW SUPPORT ADAPTER.
LH2 & LO2 MASS GAUGES	2	7	EVA	12:15	9:00	NO FAILURE ANTICIPATED	EVA SUPPORT EQUIPMENT. RMS WITH EVA CREW SUPPORT ADAPTER.
LH2 & LO2 THERMAL VENT SYSTEMS (JOULE-THOMSON VALVE ONLY)	2	7	EVA	12:15	9:00	NO FAILURE ANTICIPATED	EVA SUPPORT EQUIPMENT. RMS WITH EVA CREW SUPPORT ADAPTER.
LH2 & LO2 TRANSFER PUMPS	2	8	EVA	13:15	11:00	2 TIMES PER LIFE OF MISSION MODEL	2ND RMS WITH GRASPING ADAPTER. EVA SUPPORT EQUIPMENT. RMS WITH EVA CREW SUPPORT ADAPTER.
GH2 & GO2 SURGE ACCUMLATORS	2	8	EVA	13:15	11:00	4 TIMES PER LIFE OF MISSION MODEL	2ND RMS WITH GRASPING ADAPTER. EVA SUPPORT EQUIPMENT. RMS WITH EVA CREW SUPPORT ADAPTER.

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Table 4-23. LTCSF Maintenance Requirements

ORU	QUANTITY PER TANK SYSTEM	TASK TIME (HR) (EA)	PRIMARY MAINTENANCE OPERATION	MANHOURS		FREQUENCY PER TANK SET	SUPPORT EQUIPMENT
				IVA (EA)	EVA (EA)		
GH2 & GO2 SURGE COMPRESSORS	2	7	EVA	12:15	9:00	2 TIMES PER LIFE OF MISSION MODEL	EVA SUPPORT EQUIPMENT. RMS WITH EVA CREW SUPPORT ADAPTER.
ELECTRICAL SYSTEM CONTROL UNIT	1	4:05	TELE-OPERATION	4:05	-	2 TIMES PER LIFE OF MISSION MODEL	1 RMS - WITH MULTIPLE SERVICING TOOL ADAPTER. CLOSED CIRCUIT TELEVISION.
GRAPPLE FITTINGS	2	3:40	EVA	11:00	4:50	NO FAILURE ANTICIPATED	EVA SUPPORT EQUIPMENT. RMS WITH EVA CREW SUPPORT ADAPTER.
LONGERON FITTINGS	4	3:40	EVA	11:00	4:50	NO FAILURE ANTICIPATED	EVA SUPPORT EQUIPMENT. RMS WITH EVA CREW SUPPORT ADAPTER.
LH2 & LO2 PRESSURANT HEAT EXCHANGER & PUMP	2	3:55	TELE-OPERATION	3:55	-	4 TIMES PER LIFE OF MISSION MODEL	1 RMS - WITH MST ADAPTER. CCTV.
LH2 & LO2 PRECHILL ACCUMULATOR	5	7	EVA	12:15	9:00	NO FAILURE ANTICIPATED	EVA SUPPORT EQUIPMENT. RMS WITH EVA CREW SUPPORT ADAPTER.

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Table 4-23. LTCSF Maintenance Requirements, Contd

ORU	QUANTITY PER TANK SYSTEM	TASK TIME (HR) (EA)	PRIMARY MAINTENANCE OPERATION	MANHOURS		FREQUENCY PER TANK SET	SUPPORT EQUIPMENT
				IVA (EA)	EVA (EA)		
RELIQUEFACTION UNIT	1	5	TELE-OPERATION	5:00	-	6 TIMES PER LIFE OF MISSION MODEL	CCTV. 1 RMS WITH MST ADAPTER.
VISUAL INSPECTION		9	EVA	14:00	13:00	ONCE PER YEAR	RMS WITH EVA CREW SUPPORT ADAPTER. EVA SUPPORT EQUIPMENT.
		4	TELE-OPERATION	4:00	-	2 TIMES PER YEAR	RMS. CCTV.

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Table 4-23. LTCSF Maintenance Requirements, Contd

MAINTENANCE OPERATION	QUANTITY	TOTAL TIMES OPERATION PERFORMED	TOTAL TASK TIME-HRS	TOTAL MANHOUR REQ	
				IVA	EVA
MAIN TRUSS STRUCTURE	1000				
- VISUAL INSPECTION		34	136	136	
- R/R IND. TRUSS		26	130	260	130
HANGAR INTERNAL BERTH FIXTURE AND ELECTRICAL CONNECTORS	1				
- VISUAL INSPECTION		257	21.5	21.5	
- R/R FIXTURE		12	81	141	102
EXTERNAL BERTHING FIXTURE AND ELECTRICAL CONNECTORS	1				
- VISUAL INSPECTION		514	43	43	
- R/R FIXTURE		1	6	11	7
CCTV	10				
- R/R		4	20	40	20
- ADJUST		17	68	68	

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Table 4-24. Total Manhour Requirements for OTV Support Equipment Maintenance

MAINTENANCE OPERATION	QUANTITY	TOTAL TIMES OPERATION PERFORMED	TOTAL TASK TIME-HRS	TOTAL MANHOUR REQ	
				IVA	EVA
LIGHTING					
- LIGHT BULBS	50	26	182	312	234
- R/R LIGHT FIXTURE	50	NO ANTICIPATED MAINTENANCE	-	-	-
LEAK DETECTOR	4				
- R/R		24	132	252	144
- CHECK		17	8.5	8.5	8.5
COMMUNICATION LINES					
- REMOVE & REPLACE		2	16	26	22
RMS	2				
- R/R JOINT OR DRIVE INSTRU	6	1	10	16	16
- LIGHTS	2	NO ANTICIPATED MAINTENANCE			
- TV	4	INCLUDED WITH OTHER CCTVS		-	-
- POSITION INDICATORS		INCLUDED IN RMS ACTIVATION TASK			

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Table 4-24. Total Manhour Requirements for OTV Support Equipment Maintenance, Contd

MAINTENANCE OPERATION	QUANTITY	TOTAL TIMES OPERATION PERFORMED	TOTAL TASK TIME-HRS	TOTAL MANHOUR REQ	
				IVA	EVA
EVA ADAPTER	1	1	WILL BE REPLACED	-	-
PROTECTIVE COVER	-	NO ANTICIPATED MAINTENANCE	-	-	-
HANGAR SCREEN	-	NO ANTICIPATED MAINTENANCE	-	-	-
HANGAR DRIVE MOTOR	1	1	6.3	12	7.6
SPARES HOLDING FIXTURES	-	1	5	10	5
CONTROL PANEL R/R	4	2	3	3	
TOTAL			868	1360	696
AVERAGE/YR			51	80	41

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Table 4-24. Total Manhour Requirements for OTV Support Equipment Maintenance, Contd

LONG TERM CRYOGENIC STORAGE FACILITY (LTCSF)

MAINTENANCE TASK	TASK TIME (HRS)	MANHOURS	
		IVA	EVA
LH2 & LO2 TRANSFER PUMP	32	53	44
GH2 & GO2 SURGE ACCUMULATORS	64	106	88
GH2 & GO2 SURGE COMPRESSORS	28	49	36
ELECTRICAL SYSTEM CONTROL UNIT	16	16	-
PRESSURANT HEAT EXCHANGER & PUMP	32	32	-
RELIQUEFACTION UNIT	60	60	-
VISUAL INSPECTION	578	748	442
TOTAL MAINTENANCE TIME/MISSION LIFE	810	1064	610
AVERAGE HOURS PER YEAR	48	63	36
PROPELLANT RESUPPLY (79 MISSIONS)	1620	2594	
AVERAGE HOURS/YEAR	95	153	

(7/15)

NOTE: ALL VALUES ROUNDED TO NEAREST WHOLE NUMBER.

Table 4-25. Total Maintenance Crew Requirements: LTCSF

		MANHOURS	
OPERATION	TOTAL	IVA	EVA
OTV TURNAROUND	900	827	73
PROPELLANT RESUPPLY	153	153	--
MAINTENANCE SUPPORT EQUIPMENT	121	80	41
LONG TERM CRYOGENIC STORAGE FACILITY (LTCSF)	99	63	36
*TOTAL	1273	1123	150

(7-15)

*EXCLUDES GROUND SUPPORT

NOTE: 17 YEAR MISSION MODEL/257 MISSION/AV 15 MISSIONS PER YEAR

Table 4-26. Manhour Requirements/Year to Operate OTV at Space Station

OPERATION	TASK HOUR REQUIREMENTS		
	ONE CREW MEMBER	2 CREW MEMBERS	3 CREW MEMBERS
OTV TURNAROUND	144.5 HRS.	323 HRS	36.5 HRS.
PROPELLANT RESUPPLY	153 HRS.	--	--
MAINTENANCE SUPPORT EQUIPMENT	59.5 HRS.	--	20.5 HRS.
LTCSF	45 HRS.	--	18 HRS.
*TOTAL TASK HOURS/YEAR	402 HRS.	323 HRS	75 HRS.

THE CREW MEMBERS SKILL LEVEL AND TYPE
SPACECRAFT SYSTEMS TECHNICIANS

*TOTAL MANHOURS EQUALS 1273

Table 4-27. Task Hour Requirements by Crew Size Per Year

SECTION 5

OTV DESIGN AND INTERFACE REQUIREMENTS

Using the results and recommendations of the turnaround operations analysis and definition of the baseline GBOTV and SBOTV, we identified and defined OTV design and interface requirements for basing on the ground and at the Space Station. The following areas were investigated and descriptions of them are covered in section:

a. Accessibility

b. Modularity

c. Size and weight of ORU

d. ORU attachment and removal provisions

e. Handling and mating provisions

f. Payload mating provisions

g. Accommodations for mechanical, fluid, and electrical disconnects

5.1 GROUND-BASED OTVs (GBOTV)

The cargo bay (ballute) OTV, the ACC OTV, and the UCV OTV are addressed in the following paragraphs.

5.1.1 GROUND-BASED CARGO BAY (BALLUTE) OTV. Figure 5-1 is a picture of the cargo bay OTV which was the baseline we used in the analysis. This concept was developed by Boeing in the phase 4 OTV Definition Studies. Figure 5-2 shows the cargo bay OTV launch and retrieval configuration. The Orbiter cargo bay allows enough clearance for the cargo bay GBOTV and either a payload or auxillary propellant tank module no greater than 20 feet in length. This leaves 5 feet of clearance from the forward payload face to the forward cargo bay bulkhead for EVA entrance to the cargo bay.

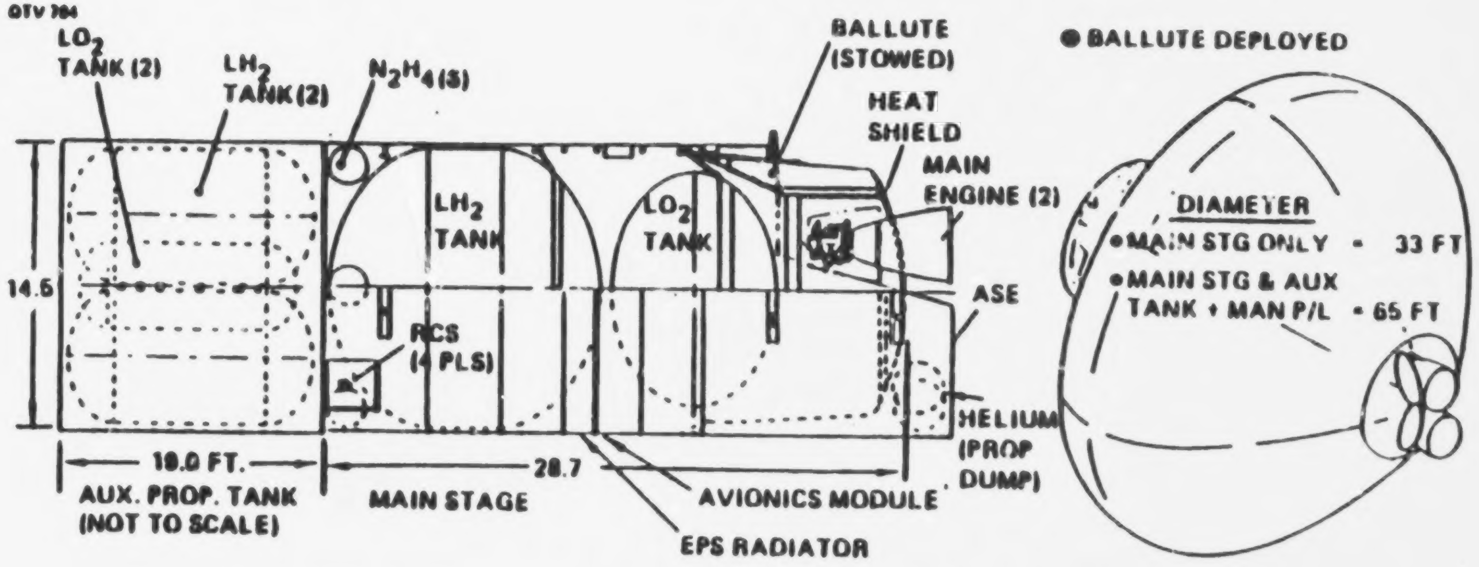
The airborne support structure is similar in size and cargo bay mounting to the Shuttle CISS.

Longeron and keel fittings at station 876 in addition to the ASE are used to support the core OTV with a 20-feet or shorter payload.

Longeron and keel fittings at station 648 and a keel fitting at station 876 in addition to the ASE can be used to support the OTV configured with the auxillary propellant tank module attached.

The OTV is returned to Earth in the cargo bay using longeron supports at stations 648 and 876 and a keel fitting at station 876. This arrangement maintains the proper shuttle center of gravity.

C-3



UNIQUE FEATURES

- BALLUTE–SAME AS SB OTV
- HEAT SHIELD–SAME AS SB OTV
- MAIN STAGE
  - USED ON ALL FLIGHTS
- AUX. PROP. TANK
  - USED ON 36 FLIGHTS
- MAIN STAGE ATTACHED TO AUX. TANK/PAYLOAD AT STATION

WEIGHT SUMMARY (LBS)

	10K NET DELIV	MAN SORTIE (7.5K)	
	MAIN	MAIN	AUX
● DRY	7996	9987	3401
● MAIN PROP	47698	47698	33722
● OTHER FLUIDS	768	1700	---
● STG STARTBURN	56461	59385	37123
● PAYLOAD (NET)	10000	---	7500
● PAYLOAD RACK	1000	---	---
● ASE	6390	6390	6390
LIFTOFF	73851	65775	51013

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Figure 5-1. Ground-Based Cargo Bay (Ballute) OTV

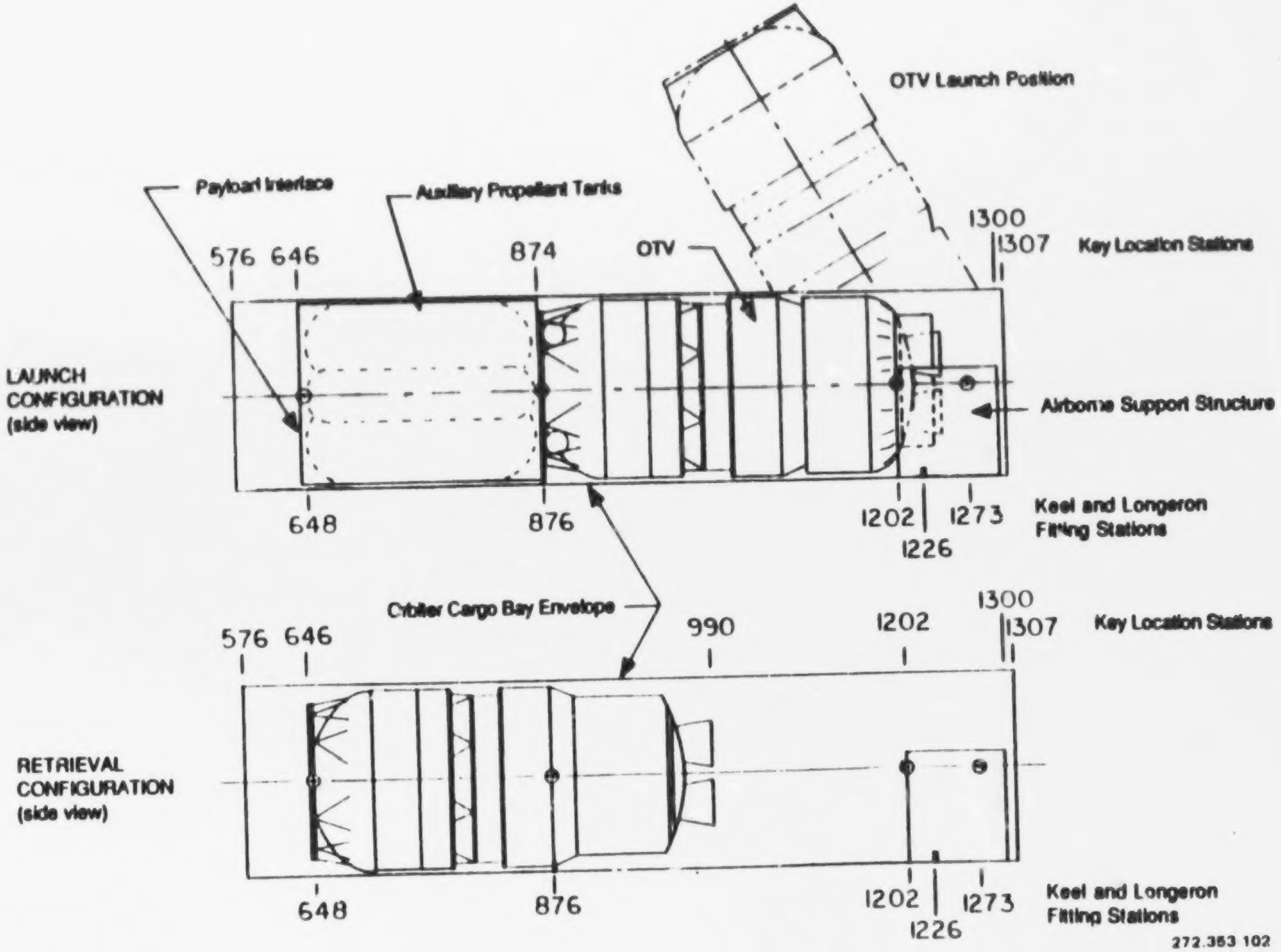

Figure 5-2. Ground-Based Cargo Bay (Ballute) OTV Launch and Retrieval Configuration

The GBOTV system has six major interfares (see Figure 5-3). These are:

1) Orbiter/ GSE.
2) ASE/Orbiter.
3) ASE/OTV.
4) OTV/Auxillary propellant tanks.
5) OTV/Payload.
6) OTV/Aerobrake.

The auxillary propellant tanks are used for heavy lift missions and not carried on every mission. When the auxillary tanks are used two ground launches are required, one for the OTV and one for the payload. A heavy lift mission would require on-orbit assembly of the payload, a ballute aerobrake is assumed to be attached to the vehicle before launch. At the conclusion of the mission, the ballute and auxillary propellant tanks would be jettisoned before the OTV is loaded back into the Orbiter.

There are eight external Orbiter interface connections dedicated to OTV support. These are:

1) H_2 Purge Vent.
2) GH_2 Ground Vent.
3) He Fill/Drain.
4) GH_2 Boost Phase Vent.
5) LH_2 Fill/Drain.
6) LO_2 Vent Dump.
7) LO_2 Fill/Drain.
8) LH_2 Dump.

The H_2 Purge Vent and LO_2 Vent/Dump are used to purge any fuel or oxidizer that leaks out of the disconnects in the lines running from the Orbiter to the OTV.

The GH_2 Ground Vent and LO_2 Vent Dump are used to vent propellants during ground operations. The LO_2 Vent Dump is also used to vent GO_2 during ascent. The GH_2 Boost phase Vent on the Orbiter tail is used to vent GH_2 during flight to avoid any mixing of fuel and the Orbiter exhaust plume.

The LH_2 Dump and LO_2 Vent Dump are used in an emergency situation to dump all propellants.

The LO_2 and LH_2 Fill/Drain connections are used to ground load and drain propellants.

The He interface is used to purge the vehicle insulation and pressurize the RCS and vehicle propellants.

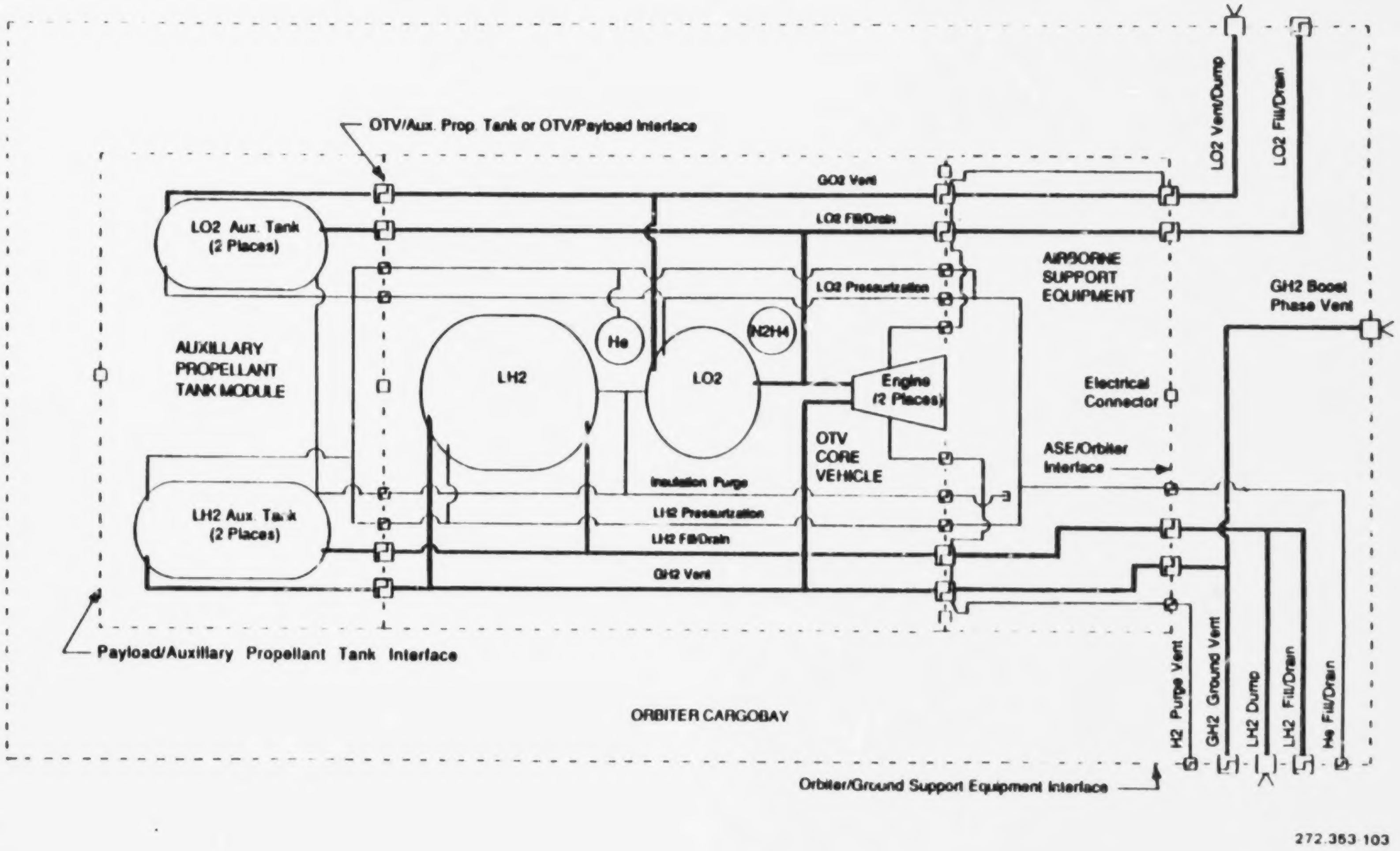

Figure 5-3. Ground-Based Cargo Bay (Ballute) Interface Schematic

N_2H_4 and fuel cell reactants are loaded prior to OTV/Orbiter integration, therefore no interfaces are shown.

Air conditioning is normally provided in the Orbiter cargo bay, therefore no dedicated interface is required.

Figure 5-4 shows the above interfaces on the Orbiter.

5.1.2 GROUND-BASED ACC OTV. Figure 5-5 is a picture of the ACC OTV which was the baseline we used in the analysis. This concept was developed by Martin in the Phase A OTV Definition Studies.

5.1.2.1 Design And Interface Requirements. The ground based aft cargo carrier (ACC) OTV system has five major interfaces (see Figure 5-6). These are:

1) ACC/Ground Support Equipment.

2) ACC/OTV.

3) OTV/Payload.

4) OTV/Propellant Tanks (2 places).

5) OTV/Aerobrake.

The OTV is composed of three LRUs. These are the two (LO_2 and LH_2) propellant tanksets and the aerobrake. These are required to enable placement of the OTV in the Orbiter cargo bay after completion of the mission.

The OTV separates from the External Tank ACC on orbit and the OTV is joined to the payload stored in the Orbiter. Upon completion of the mission the four propellant tanks and aerobrake are jettisoned from the OTV and only the core vehicle is loaded in the Orbiter for the return mission to Earth, or the aerobrake is discarded and the four propellant tanks are removed and loaded in the Orbiter cargo bay with the OTV core vehicle for the return to Earth.

The external ACC ground interface connections dedicated to OTV support are:

1) He Fill/Drain	-used to load helium for pressurizing the propellant tanks and RCS flight.
2) GH_2 and GO_2	-for ground and inflight venting of propellant gases.
3) LH_2 and LO_2	-for ground loading and dumping of propellants.
4) LH_2 and LO_2 Pressurization	-for ground pressurization of the propellant tanks.
5) Insulation Purge	-to keep tank insulation free of contaminates, which could freeze and reduce insulation capability.

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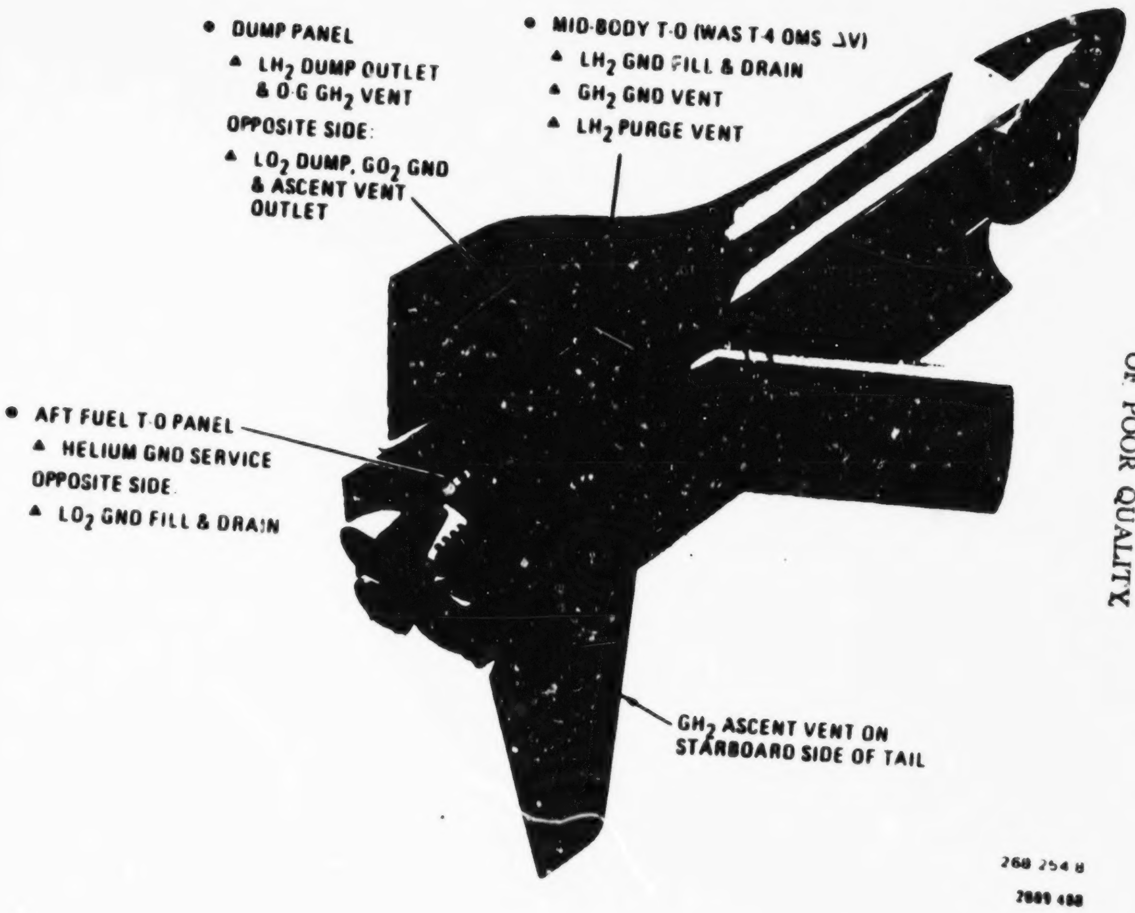
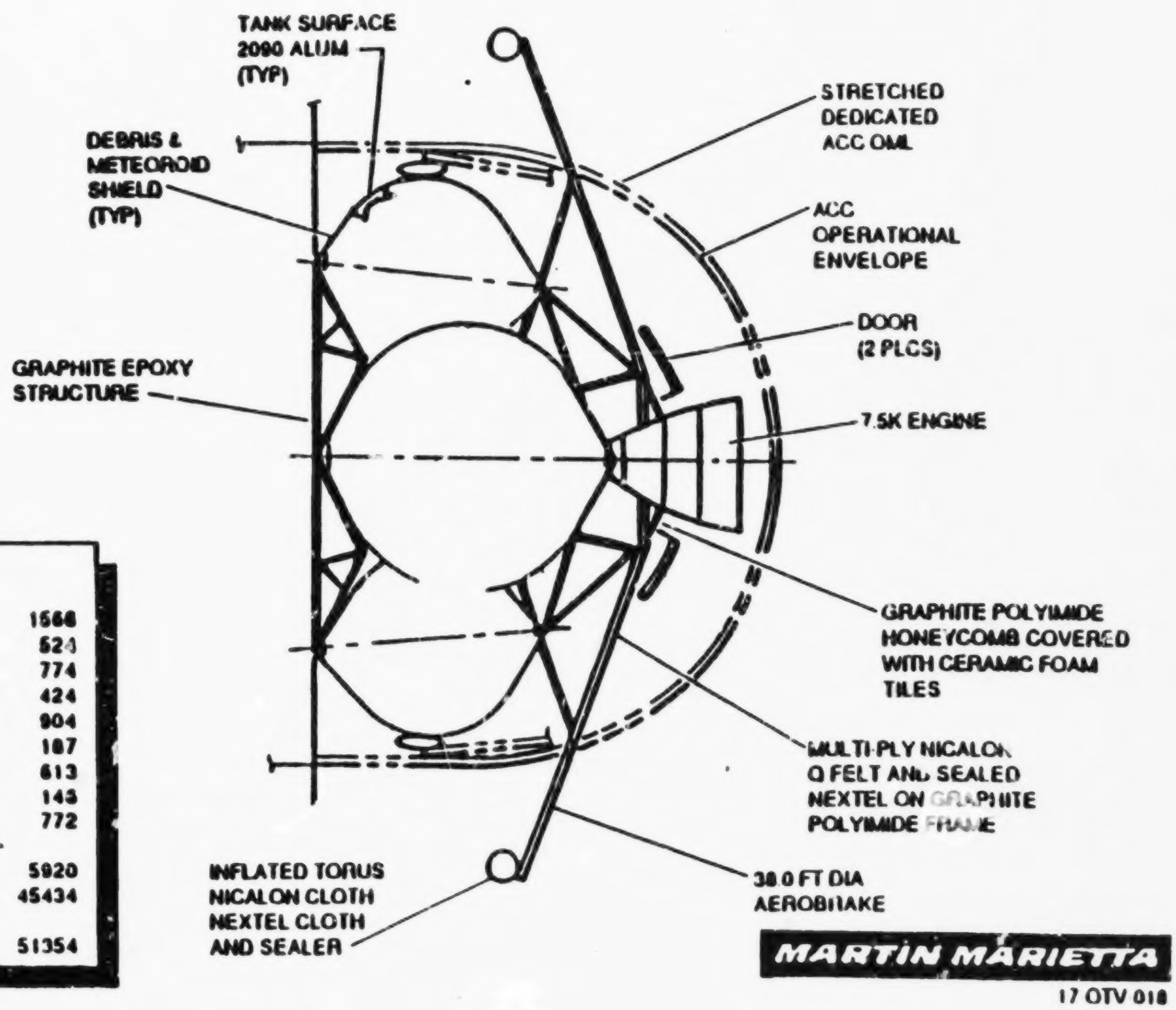

● DUMP PANEL
▲ LH_2 DUMP OUTLET & 0-G GH_2 VENT
OPPOSITE SIDE:
▲ LO_2 DUMP, GO_2 GND & ASCENT VENT OUTLET
● MID-BODY T-0 (WAS T-4 OMS ΔV)
▲ LH_2 GND FILL & DRAIN
▲ GH_2 GND VENT
▲ LH_2 PURGE VENT
● AFT FUEL T-0 PANEL
▲ HELIUM GND SERVICE
OPPOSITE SIDE:
▲ LO_2 GND FILL & DRAIN
GH_2 ASCENT VENT ON STARBOARD SIDE OF TAIL
268 254 8
2889 488

Figure 5-4. Ground-Based Cargo Bay OTV/Orbiter Interfaces


TANK SURFACE 2090 ALUM (TYP)
DEBRIS & METEOROID SHIELD (TYP)
GRAPHITE EPOXY STRUCTURE
INFLATED TORUS NICALON CLOTH NEXTEL CLOTH AND SEALER
STRETCHED DEDICATED ACC OML
ACC OPERATIONAL ENVELOPE
DOOR (2 PLCS)
7.5K ENGINE
GRAPHITE POLYIMIDE HONEYCOMB COVERED WITH CERAMIC FOAM TILES
MULTI-PLY NICALON Q FELT AND SEALED NEXTEL ON GRAPHITE POLYIMIDE FRAME
38.0 FT DIA AEROBRAKE
MARTIN MARIETTA
17 OTV 018

WEIGHT	
AEROBRAKE	1568
TANKS	524
STRUCTURE	774
ENVIRONMENTAL CONTROL	424
MAIN PROPULSION	904
ORIENTATION CONTROL	187
ELECTRIC SYSTEMS	613
G, N & C	145
CONTINGENCY 15%	772
DRY WEIGHT	5920
PROPELLANTS, ETC.	45434
LOADED WEIGHT	51354

Figure 5-5. Ground-Based ACC OTV

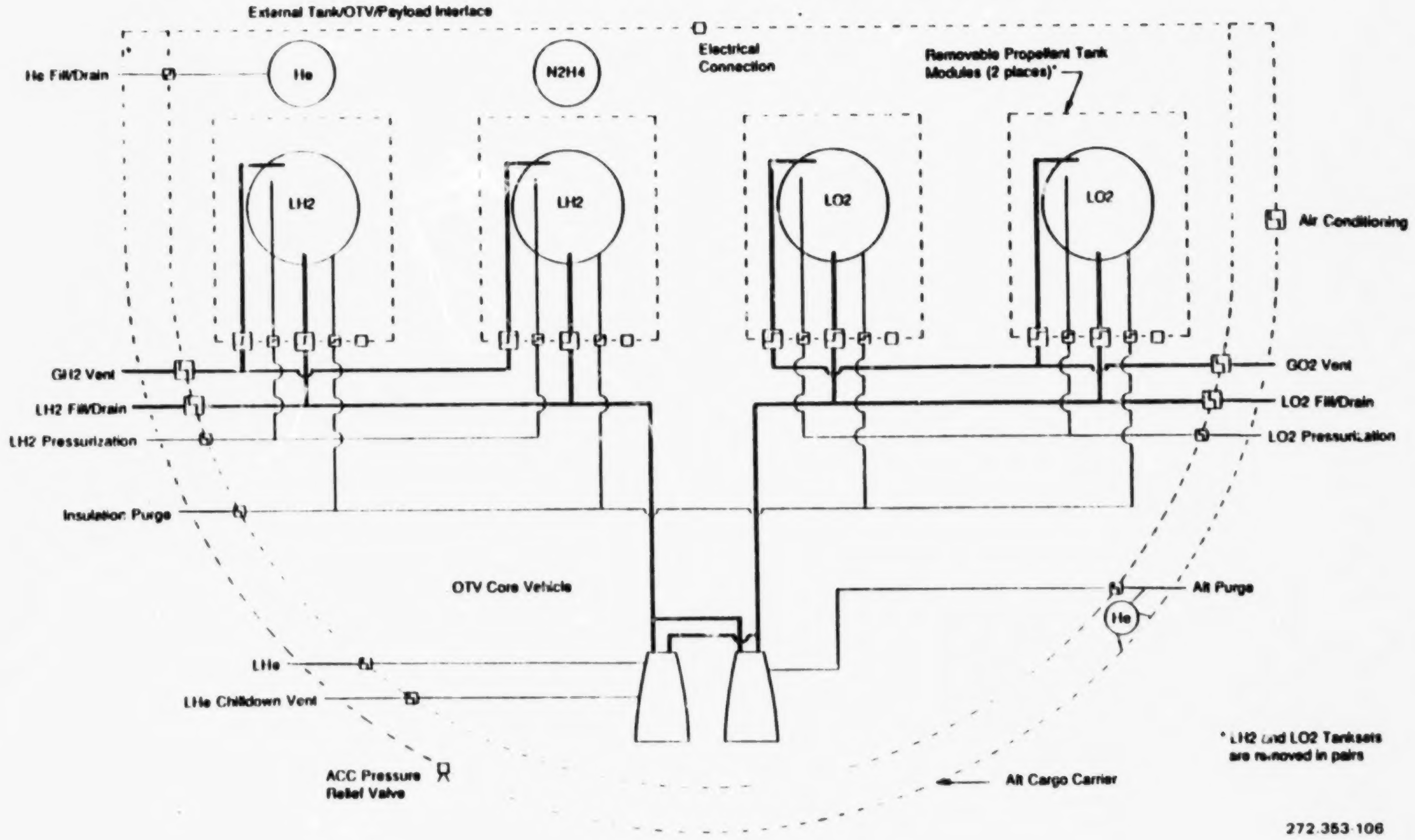


Figure 5-6. Ground-Based ACC OTV Interface Schematic

6) LHe	-to chilldown the engine on the ground. Chilling the engines reduces propellant requirements.
7) LHe Chilldown Vent	-to Vent LHe away from engines.
8) ACC Pressure Relief Valve	-to relieve ACC pressure buildup on ground and during boost.
9) Aft Purge	-to remove contaminates from engine lines on ground and during boost phase.
10) Air Conditioning	-for cooling of avionics on ground.
11) Electrical	-for power and data transfer

N_2H_4 and fuel cell reactants are loaded prior to OTV ACC fairing installation, therefore, no interfaces are shown.

5.1.2.2 ACC OTV Returns To Earth In Orbiter Cargo Bay. All elements of the ACC OTV, with the exception of the aerobrake, can be returned to Earth in the Shuttle at the conclusion of a mission (see Figure 5-7.) The aerobrake material is unable to be reused if it is folded after a mission, therefore, returning it to Earth serves no purpose.

The disassembly process requires the following:

1) Remote Manipulator System (RMS).
2) Handling and Positioning Aid (HPA).
3) Payload Installation and Deployment Aid (PIDA).
4) Miscellaneous RMS end Effectors and Tools.

OTV disassembly would be accomplished in the following manner. At the conclusion of the mission, the OTV would jettison the aerobrake or just the fabric covering. The OTV would then be captured by the Shuttle RMS and placed on two PIDAs, which would hold the core vehicle while the tanks were removed. The propellant tanks would be removed in two sections (each containing one LO_2 and one LH_2 tank). Two EVA astronauts, the RMS, and the HPA would be required to disassemble the OTV. The astronauts and the RMS would disassemble the OTV while the HPA would then collapse the OTV core structure, so that the HPA could place it in the Shuttle cargo bay.

The core structure of the OTV must be collapsed to enable placement of the entire OTV in one Shuttle cargo bay.

This disassembly process has been estimated to require at least 9 hours of EVA. Thus, approximately two EVA excursions would be required to place the OTV in the cargo bay.

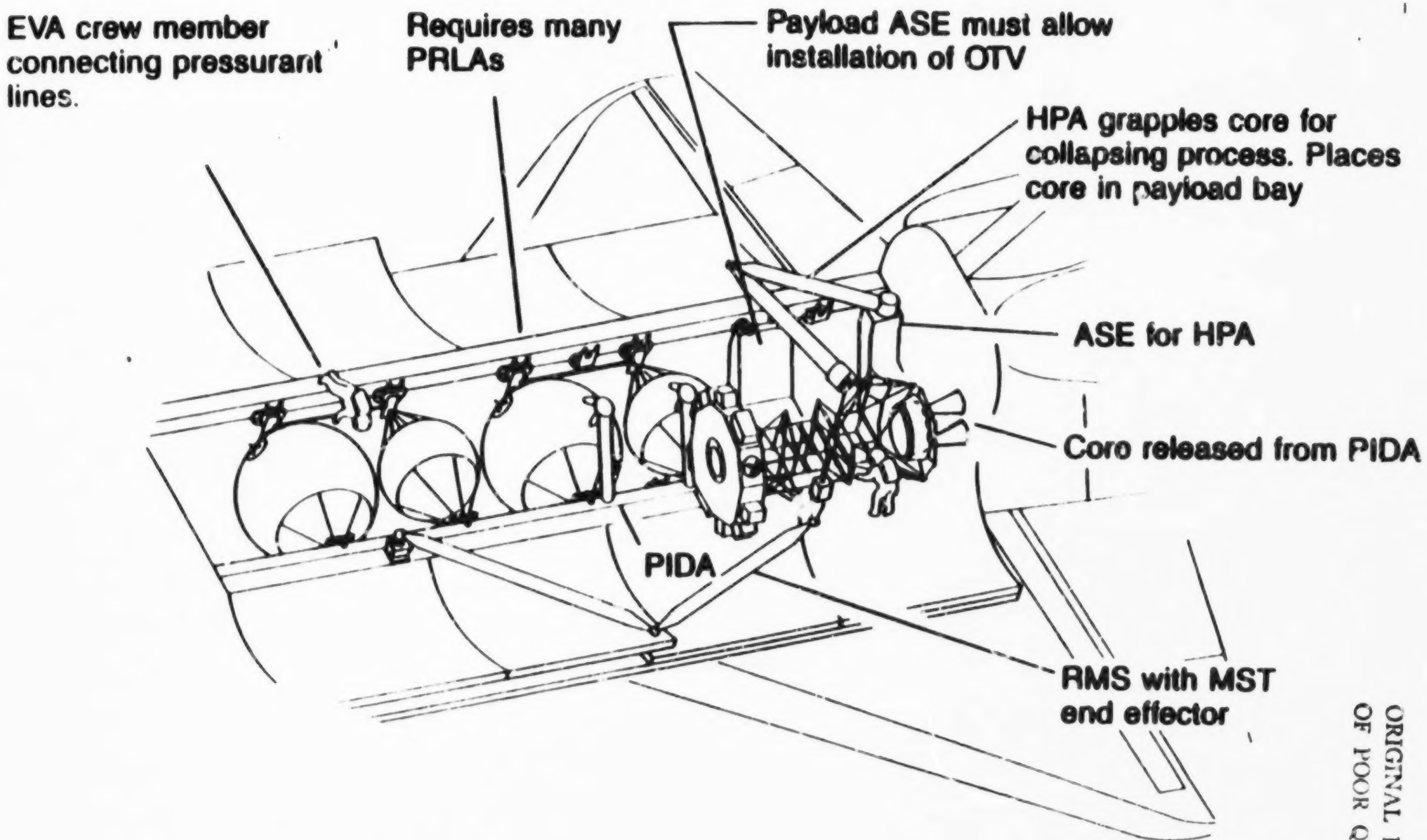

EVA crew member connecting pressurant lines.
Requires many PRLAs
Payload ASE must allow installation of OTV
HPA grapples core for collapsing process. Places core in payload bay
ASE for HPA
Core released from PIDA
PIDA
RMS with MST end effector

Figure 5-7. Ground-Based ACC OTV Disassembly and Return

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The ground-based ACC OTV is placed in the Orbiter in three sections, two LH_2 and LO_2 tanksets and a collapsed core vehicle, (the aerobrake is not returned) (see Figure 5-8).

The LO_2 tanks were assumed to be 7 feet 10 inches in diameter and the LH_2 tanks were assumed to be 11 feet in diameter. The core vehicle was assumed to have a flight length of 21 feet 9 inches and a collapsed length of 15 feet 4 inches. This storage condition was achieved by retracting the engines and collapsing the core vehicle support struts. These dimension allow 4.5 feet of clearance between the EVA airlock entrance and the first LO_2/LH_2 tankset.

Manned safety considerations would probably require venting the LO_2 and LH_2 tanks to space prior to loading them into the Orbiter cargo bay. Therefore pressurization and electrical interfaces would be required between the Orbiter and OTV to maintain tank pressurization and prevent tank collapse during Orbiter descent.

5.1.3 UCV. The UCV OTV used in this study was the 52K and 74K payload capacity OTV conceptualized by Martin Marietta and shown in Figure 5-9 and 5-10.

5.1.3.1 Design And Interface Requirements. The UCV-launched GBOTV system has five major interfaces (See Figure 5-11):

a. OTV GSE.

b. UCV/OTV.

c. OTV/Payload.

d. OTV/Propellant Tanks (4 places)

e. OTV/Aerobrake.

The OTV is composed of five LURs. These are the two LO_2 tanksets, the two LH_2 tanksets and the aerobrake. These are required to enable placement of the OTV in the Orbiter cargo bay after completion of the mission.

The OTV separates from the UCV on orbit and the OTV then places its payload into the proper orbit. Upon completion of a normal mission, the two LH_2 tanks and aerobrake are jettisoned from the OTV and the core vehicle and the two LO_2 tanks are loaded in the Orbiter for the return mission to Earth. At the conclusion of a manned mission, three propellant tanks and the aerobrake are jettisoned from the OTV and the core vehicle and one LO_2 tank are loaded in the Orbiter for the return mission to Earth. These scenarios are based on Martin Marietta information on which OTV components will fit in the Orbiter cargo bay.

The external ground interface connections dedicated to OTV support are:

a. He Fill/Drain	-used to load helium for pressurizing the propellant tanks and RCS in flight.
b. GH_2 and GO_2 Vents	-for ground and inflight venting of propellant gasses.
c. LH_2 and LO_2 Fill/Drain	-for ground loading and dumping of propellants.

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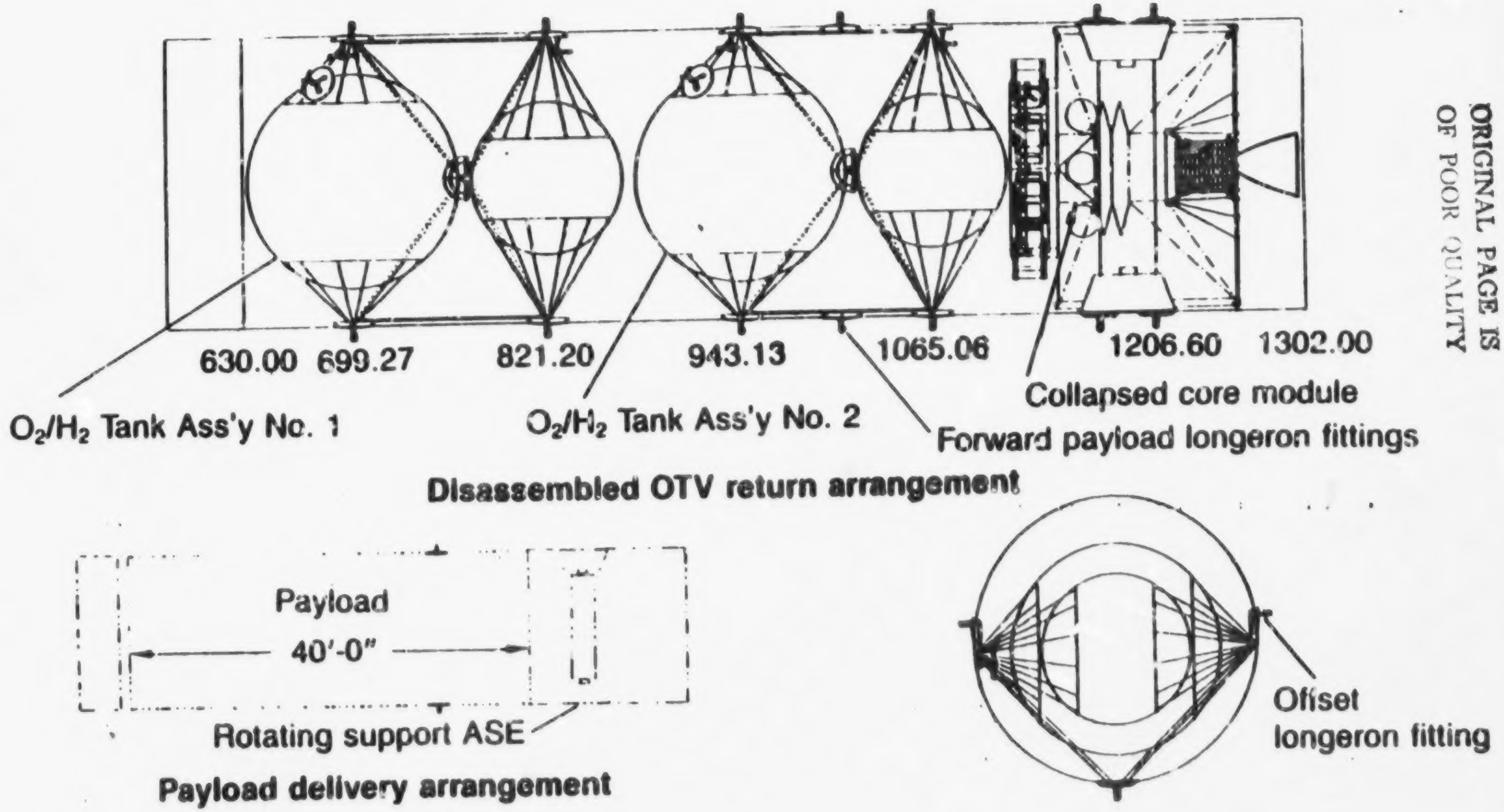
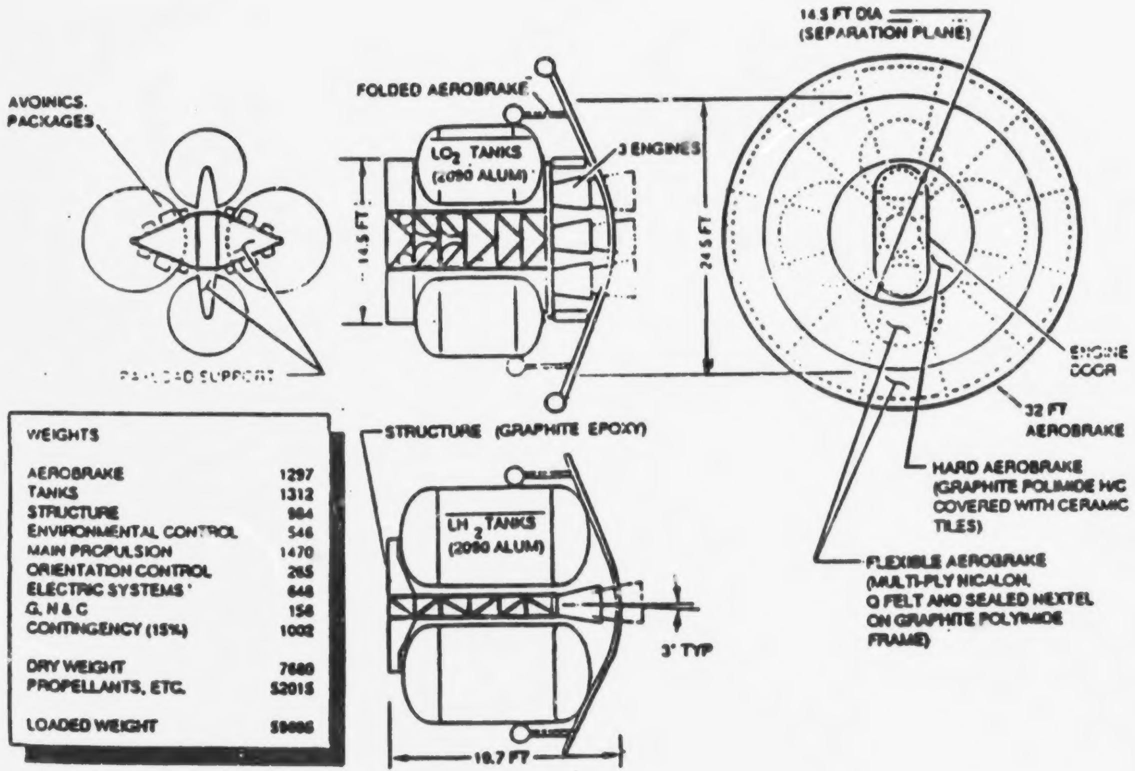

630.00
699.27
821.20
943.13
1065.06
1206.60
1302.00
Collapsed core module
O_2/H_2 Tank Ass'y No. 1
O_2/H_2 Tank Ass'y No. 2
Forward payload longeron fittings
Disassembled OTV return arrangement
Payload
40'-0"
Rotating support ASE
Payload delivery arrangement
Offset longeron fitting

Figure 5-8. Ground-Based ACC OTV Return From Orbit Arrangement (in Orbiter Cargo Bay



WEIGHTS	
AEROBRAKE	1297
TANKS	1312
STRUCTURE	984
ENVIRONMENTAL CONTROL	546
MAIN PROPULSION	1470
ORIENTATION CONTROL	265
ELECTRIC SYSTEMS	648
G, N & C	156
CONTINGENCY (15%)	1002
DRY WEIGHT	7680
PROPELLANTS, ETC.	52015
LOADED WEIGHT	59695

Martin Marietta 52K Ground Based OTV Concept

272.353-109

Figure 5-9. Ground-Based 52K Unmanned Cargo Vehicle OTV

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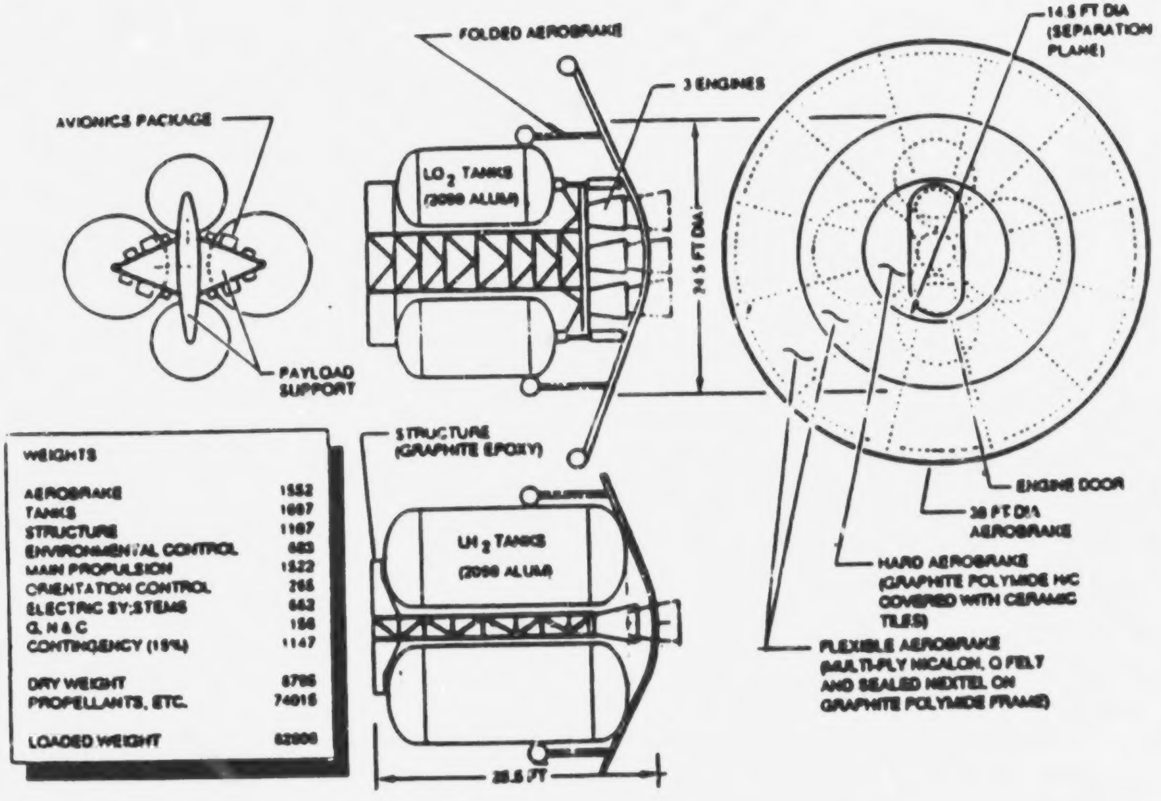
AVIONICS PACKAGE
PAYLOAD SUPPORT
FOLDED AEROBRAKE
3 ENGINES
LO_2 TANKS (2090 ALUM)
24.5 FT DIA
14.5 FT DIA (SEPARATION PLANE)
ENGINE DOOR
38 FT DIA AEROBRAKE
HARD AEROBRAKE (GRAPHITE POLYMIDE H/C COVERED WITH CERAMIC TILES)
FLEXIBLE AEROBRAKE (MULTI-PLY NICALON, Q FELT AND SEALED NEXTEL ON GRAPHITE POLYMIDE FRAME)
STRUCTURE (GRAPHITE EPOXY)
LH_2 TANKS (2090 ALUM)
28.5 FT

WEIGHTS	
AEROBRAKE	1552
TANKS	1687
STRUCTURE	1107
ENVIRONMENTAL CONTROL	683
MAIN PROPULSION	1522
ORIENTATION CONTROL	266
ELECTRIC SYSTEMS	662
G, N & C	156
CONTINGENCY (15%)	1147
DRY WEIGHT	8785
PROPELLANTS, ETC.	74015
LOADED WEIGHT	82800

Martin Marietta 74K Ground Based OTV Concept

272.353.110

Figure 5-10. Ground-Based 74K Unmanned Cargo Vehicle OTV

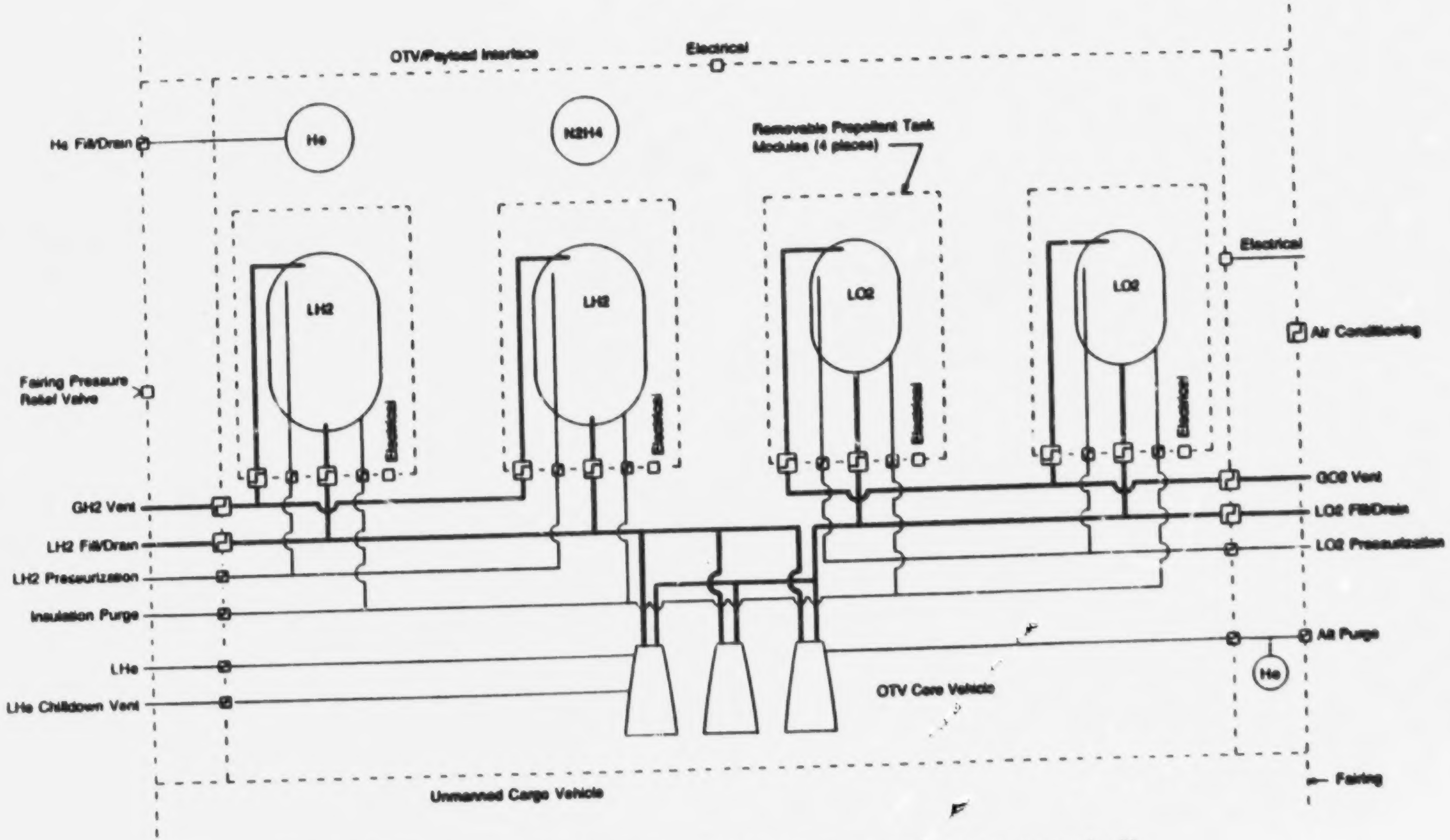

Figure 5-11. OTV Interface Schematic (Ground-Based UCV Launched)

d. LH2 and LO2 Pressurization	-for ground pressurization and purge of the propellant tanks.
e. Insulation Purge	-to keep tank insulation free of contaminates, which could freeze and reduce insulation capability.
f. LHe	-to chilldown the engine on the ground. Chilling the engines reduces propellant requirements.
g. LHe Chilldown Vent	-to vent LHe away from engines.
h. Fairing Pressure Relief Valve	-to relieve fairing pressure buildup on ground and during boost.
i. Aft Purge	-to remove contaminates from engine lines on ground and during boost phase. Also for tank insulation purge during boost.
j. Air Conditioning	-for cooling of avionics on ground.
k. Electrical	-for power and data transfer.

N_2H_4 and fuel cell reactants are loaded prior to payload fairing installation, therefore, no interfaces are shown.

5.1.3.2 UCV OTV Disassembly And Return To Earth On Orbiter Cargo Bay. Figure 5-12 shows the UCV GBOTV flight operations where the OTV is launched on the UCV and after its mission is returned to Earth in the Orbiter.

All elements of the 52K UCV OTV, with the exception of the aerobrake and LH_2 tanks, can be returned to Earth in the Shuttle at the conclusion of a mission (see Figure 5-13). The aerobrake material is unable to reused if it is folded after a mission, therefore, returning it to Earth serves no purpose. Due to the larger size of the 74K OTV, the aerobrake, both LH_2 tanks, and one LO_2 tank cannot be placed in the Orbiter.

The disassembly process requires the following:

a. RMS

b. HPA

c. PIDA

d. Miscellaneous RMS End Effectors and Tools

OTV disassembly would be accomplished in the following manner. At the conclusion of the mission the OTV would jettison the aerobrake and propellant tanks. The OTV would then be captured by the Shuttle RMS and placed on two PIDAs, which would hold the core vehicle while the tanks were removed. Two EVA astronauts, the RMS, and the HPA would be required to disassemble the

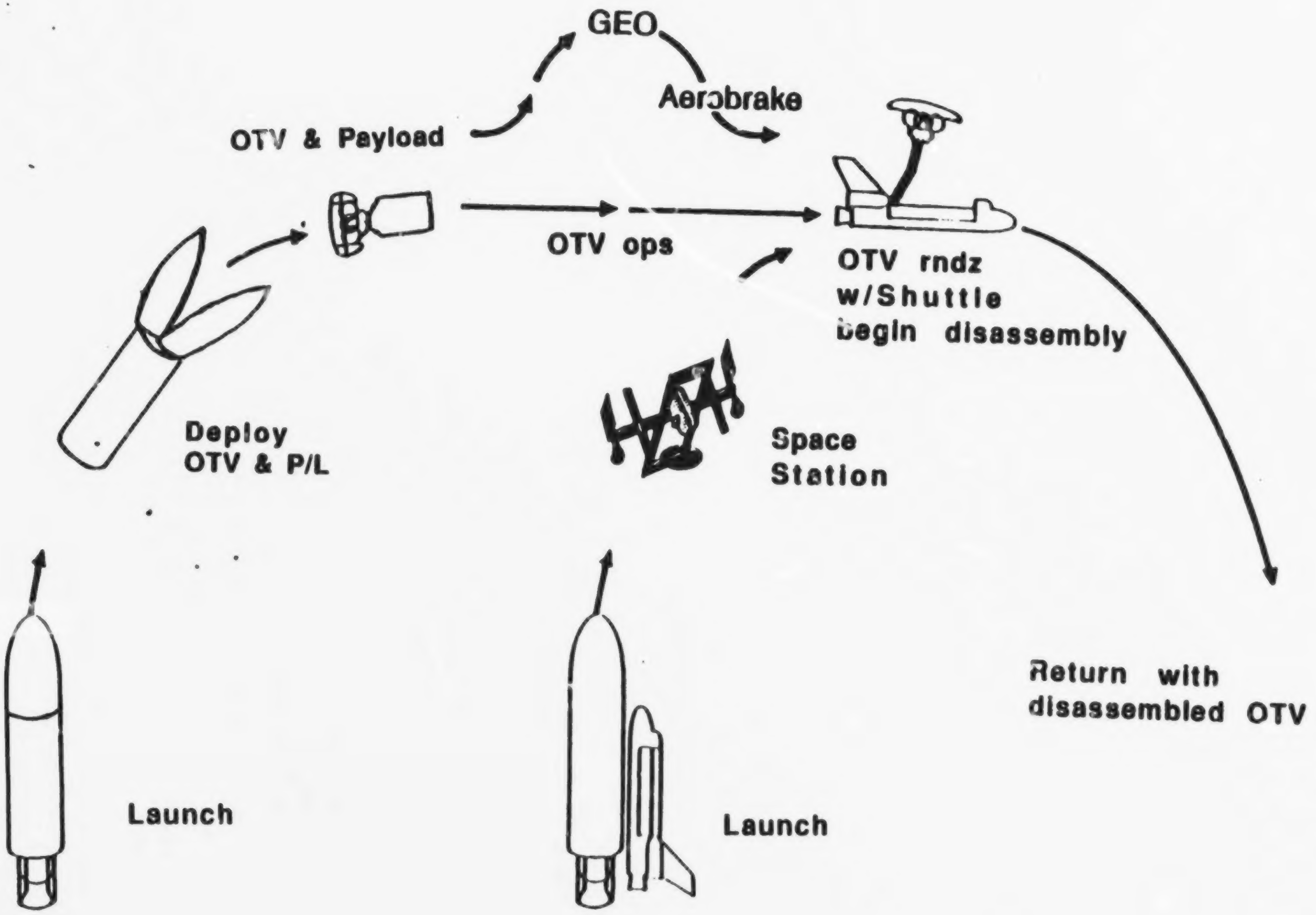

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Figure 5-12. Ground-Based UCV OTV Flight Operations

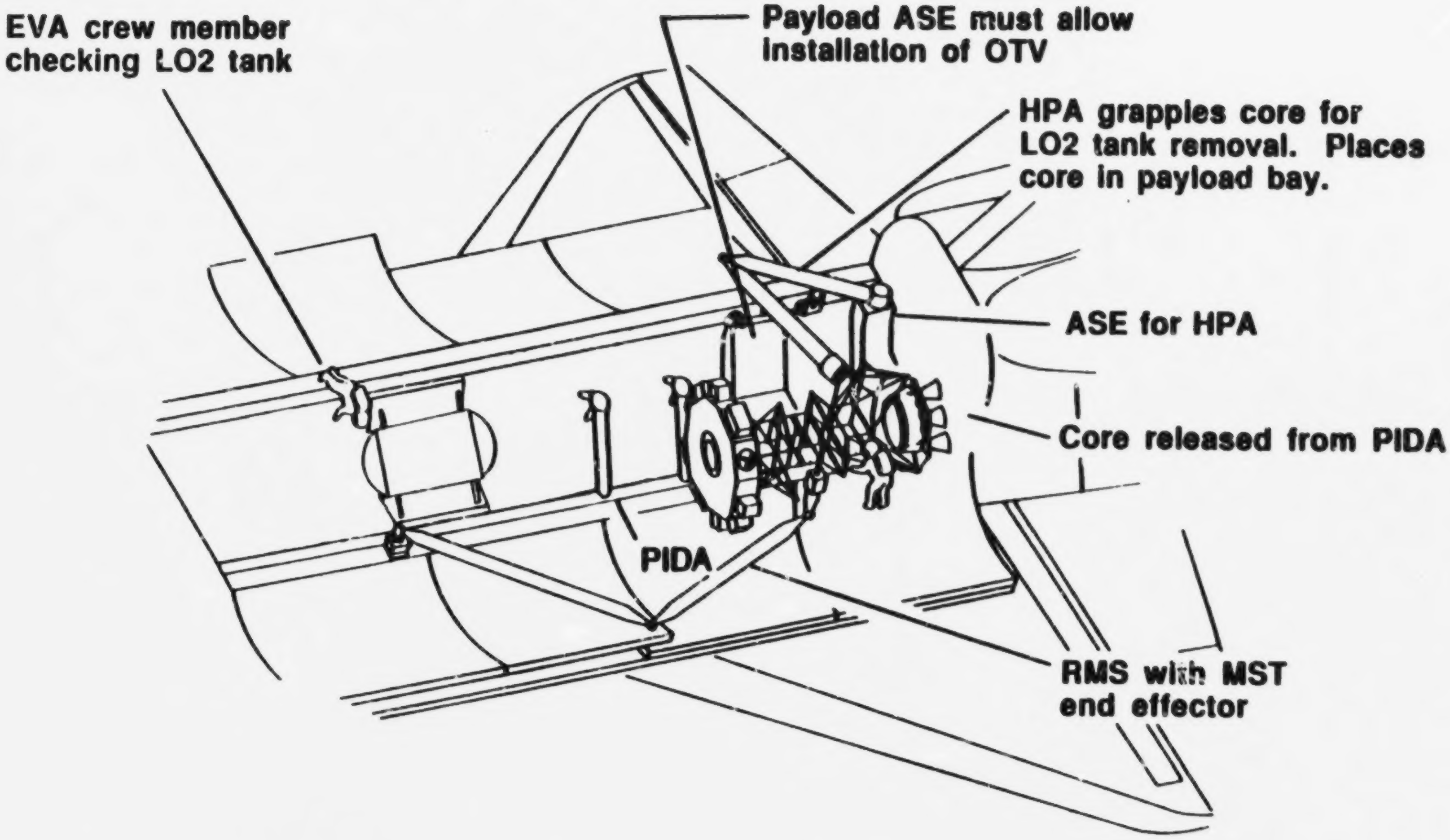

EVA crew member checking LO2 tank
Payload ASE must allow installation of OTV
HPA grapples core for LO2 tank removal. Places core in payload bay.
ASE for HPA
Core released from PIDA
PIDA
RMS with MST end effector

Figure 5-13. Ground-Based UCV OTV Disassembly and Return

OTV. The astronauts and the RMS would disassemble the LO_2 tank or tanks from the OTV while the HPA would be used to reposition the OTV on the PIDAs during disassembly. The HPA would then place the OTV core in the shuttle cargo bay.

Figure 5-14 illustrates concepts for returning the 52K and 74K OTVs back to Earth in the Orbiter.

The 54K OTV is small enough to return the core vehicle and both LO_2 tanks back to Earth. This arrangement also leaves adequate clearance in the Orbiter cargo bay for the astronauts to move around the stowed OTV components. Station numbers are shown where longeron and/or keel fittings can be placed in the Orbiter to secure either OTV components directly or OTV component support equipment.

The 72K OTV core vehicle and one LO_2 tank are also shown in their Orbiter storage positions for the return trip to Earth. Due to the larger OTV and LO_2 tank size, only one LO_2 tank can be returned to Earth with the OTV core vehicle. Station numbers are also shown where longeron and/or keel fittings can be placed in the Orbiter to secure either OTV components directly or OTV component support equipment.

The following are the assumptions and groundrules for OTV on-orbit disassembly:

a. Aerobrake and LH_2 tanks have been jettisoned.
b. LO_2 tanks inert.
c. OTV powered down.

Total task time for disassembly of OTV and storage in the Shuttle cargo bay is 7 hours 40 minutes (see Table 5-1). This includes 5 hours 50 minutes of EVA. EVA are perform by two crew members with one crew member IVA.

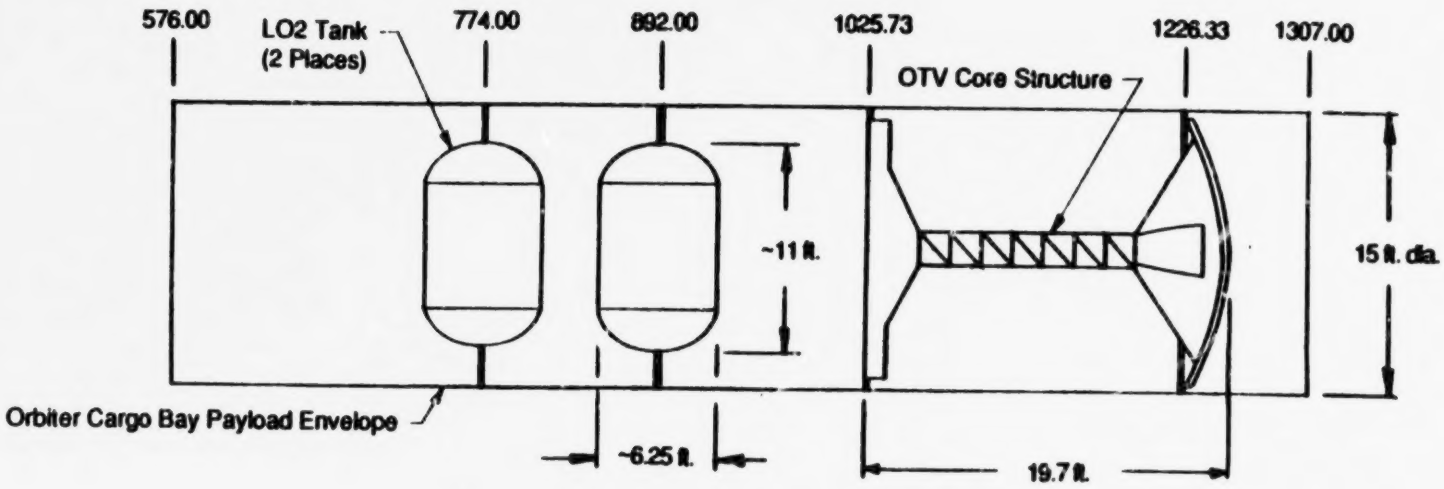
5.2 SPACE-BASED OTV (SBOTV)

Figure 5-15 is the concept of the SBOTV which was the baseline we used in the analysis. This concept is a synthesized version. It is launched dry in the cargo bay and assembled and operated in LEO at the Space Station.

The SBOTV reference configuration would require two shuttle flights for delivery to orbit (see Figure 5-16). One Shuttle flight would contain the OTV core vehicle (including avionics, LO_2 tanks, and engines), and an LH_2 tank. This would leave approximately 5 feet of cargo bay free for other payloads. The second Orbiter would contain the other two LH_2 tanks and miscellaneous cargo, (approximately 25 feet in length). This miscellaneous cargo would contain the aerobrake and possibly the payload carrier and payload adapters.

The OTV and Orbiter would require fluid and electrical interfaces to maintain and monitor tank pressures during ascent or the tanks could be vented to the atmosphere.

52K OTV RETURN FROM ORBIT ARRANGEMENT



74K OTV RETURN FROM ORBIT ARRANGEMENT

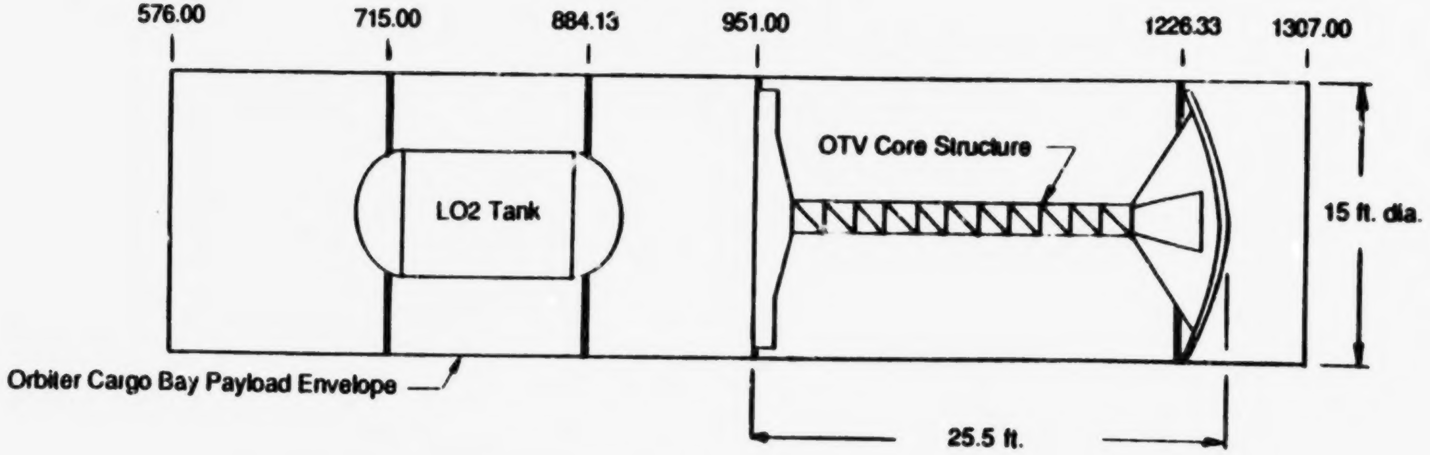


Figure 5-14. UCV-Launched OTV Return From Orbit Arrangement (in Orbiter Cargo Bay

		HOURS
DISASSEMBLE OTV		7:40
• CAPTURE OTV		1:30
- MANEUVER THE SHUTTLE WITHIN OTV CAPTURE RANGE	–	
- POSITION RMS FOR OTV CAPTURE	0:30	
- CAPTURE OTV	0:30	
- POSITION OTV IN PIDA	0:15	
- EVA CREW EGRESS AIR LOCK	0:15	
• REMOVE/STOW LO2 TANK		2:10
- GRASP MANIPULATOR FOOT RESTRAINT AND SECURE	0:10	
- TRANSLATE CREW TO LO2 TANK 1	0:05	
- DISCONNECT WIRING HARNESS	0:15	
- TRANSLATE CREW TO PROPELLANT LINE DISCONNECT	0:05	
- DISCONNECT PROPELLANT LINE FOR TANK 1	0:10	
- TRANSLATE CREW TO TOOL STORAGE AREA	0:05	
- OBTAIN MST	0:05	
- GRAPPLE LO2 TANK 1 WITH HPA	0:10	
- TRANSLATE CREW TO TANK 1	0:05	
- DISCONNECT LO2 TANK FROM CORE (2 PLACES)	0:20	

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Table 5-1. On-Orbit OTV Capture and Disassembly Task Times

		HOURS
• REMOVE/STOW LO2 TANK (CONTD)		
- TRANSLATE CREW TO SAFE AREA	0:05	
- RELEASE AND STOW MFR	0:05	
- REPOSITION RMS	0:05	
- GRASP LO2 TANK 1 WITH RMS	0:10	
- RELEASE HPA	0:05	
- POSITION TANK AT SHUTTLE	0:05	
- STOW LO2 TANK 1 IN SHUTTLE	0:10	
- RELEASE RMS	0:05	
• REMOVE LO2 TANK 2		2:30
- REPEAT REMOVE LO2 TANK 1	2:20	
- STOW HPA	0:10	
• CONNECT PRESSURE LINE		0:45
- TRANSLATE CREW TO LO2 TANK 1	0:05	
- CONNECT VENT/PRESSURIZATION LINE	0:15	
- TRANSLATE CREW TO LO2 TANK 2	0:05	
- CONNECT VENT/PRESSURIZATION LINE	0:15	
- TRANSLATE CREW TO AIRLOCK	0:05	

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Table 5-1. On-Orbit OTV Capture and Disassembly Task Times, Contd

		HOURS
• STOW OTV CORE SECTION		0:45
- REPOSITION RMS	0:05	
- GRASP OTV CORE SECTION	0:10	
- RELEASE PIDA AND STOW	0:05	
- POSITION CORE FOR STOWING	0:05	
- STOW CORE SECTION	0:10	
- RELEASE RMS AND STOW	0:10	

Table 5-1. On-Orbit OTV Capture and Disassembly Task Times, Contd

MISSION CAPABILITY	
• GEO CIRCULAR	
---EXPENDABLE	31,890 LB
---REUSABLE	20,000 LB
• MAXIMUM DURATION	60 HRS
• GEO SERVICE STATION LOGISTICS	12,000 UP/2,000 DOWN
STAGE DESCRIPTION	
• DRY WEIGHT	9,070 LB
• BURNOUT WEIGHT	10,460 LB
• USABLE MAIN PROPELLANT	58,540 LB
• STAGE IGNITION WEIGHT	69,000 LB
• AIRBORNE SUPPORT EQUIPMENT	TBD
PROPULSION	
• PROPELLANT TYPE	O_2/H_2 (1 ATM)
• NO MAIN ENGINE	2
• MIXTURE RATIO/ISP	6:1/485
• AVERAGE THRUST LEVEL	5,000 LB (PER ENG.)
• RCS PROPELLANT	N_2H_4
AVIONICS	
• TYPE	3 STRING
• POWER	FUEL CELL (PROPELLANT GRADE REACTANTS)

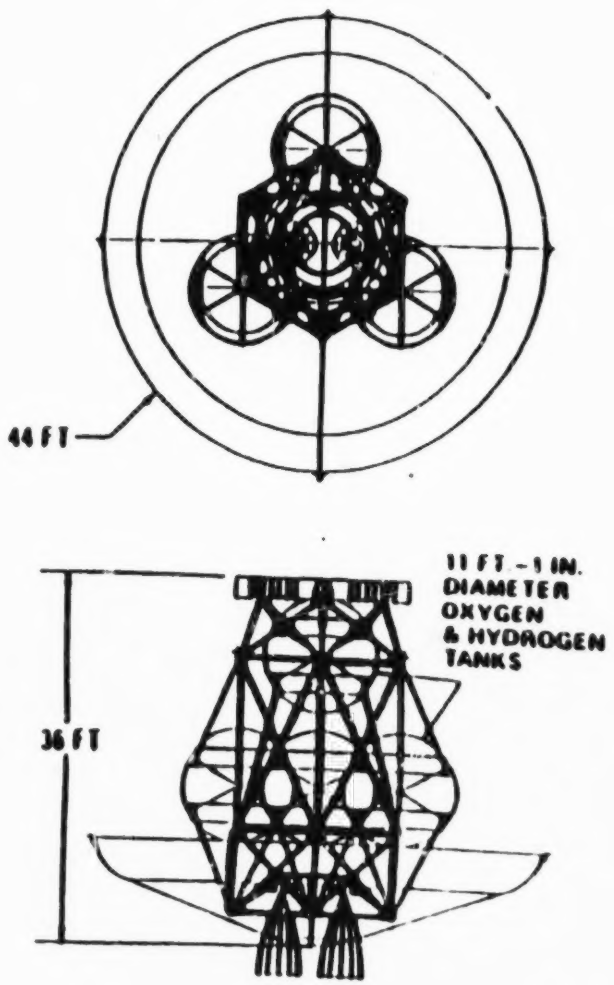

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Figure 5-15. SBOTV Reference Configuration (Synthesized Version)

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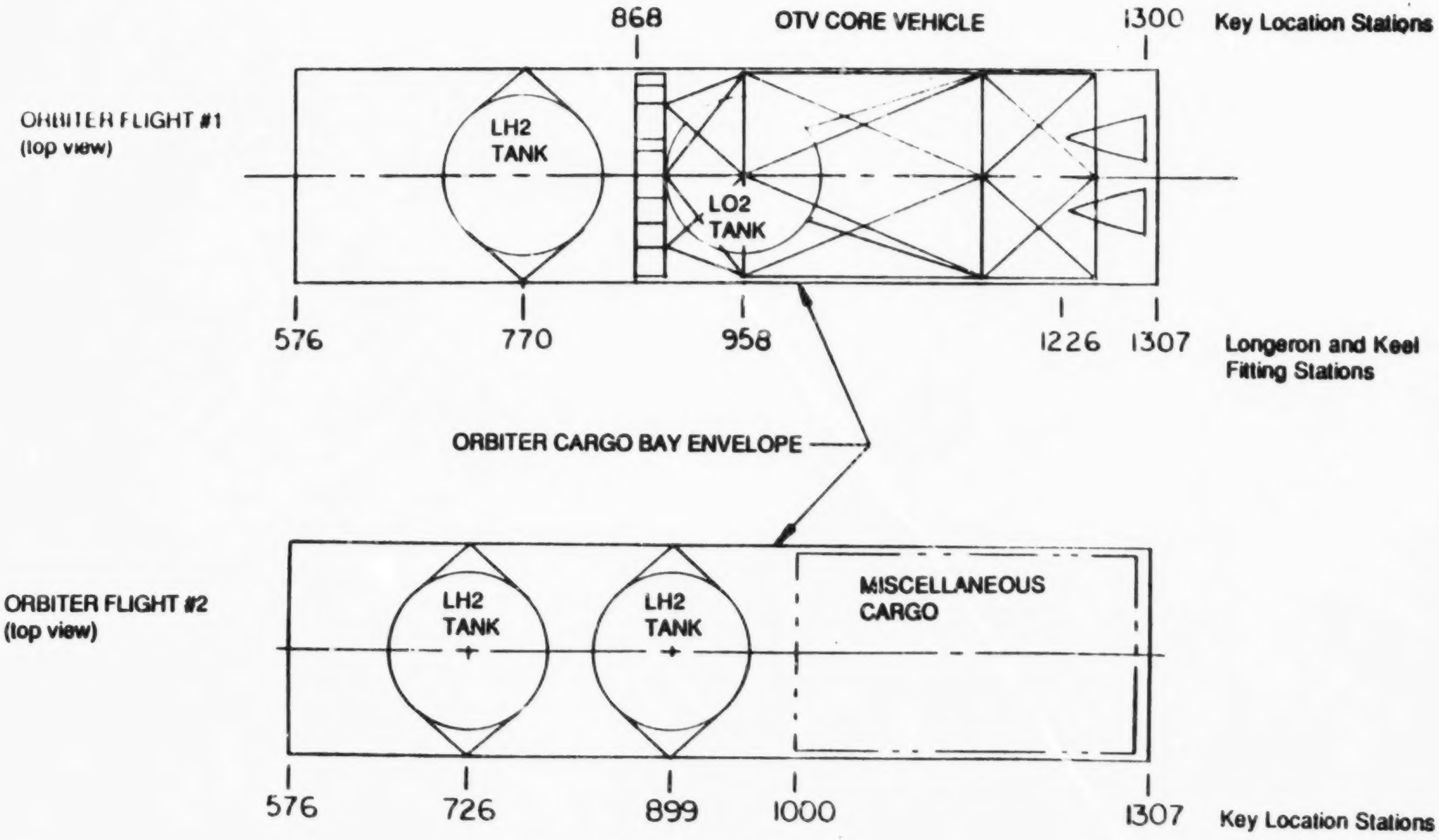

Figure 5-16. SBOTV Reference Configuration: Launch to Orbit

The vehicle consists of the following primary ORU (see Figure 5-17):

a. Engine (2 places).
b. RCS thruster modules (2 places min.).
c. Oxidizer tank.
d. Avionics core structure.
e. Aerobrake Structure.
f. Aerobrake thermal protection.
g. Fuel Cell H_2O Module (1 place min.).
h. Fuel Cell Reactant Module (O_2).
i. He bottle (1 place min. for RCS pressurization).
j. Fuel tanks (3 places).
k. RCS fuel storage (1 place min.).
l. Avionics boxes (10 places).
m. Payload adapters.
n. Multiple payload carrier.
o. Fuel Cell Reactant Module (H_2).

Due to the configuration of the vehicle, replacement of the oxidizer tank requires removal of the avionics, however the oxidizer tank will only be removed for repairs. All other ORUs should be replaceable without removing any other ORUs other than the aerobrake.

The SBOTV has only mechanical interfaces with its ground launch vehicle all propellants will be loaded on orbit at the Space Station propellant depot. The SBOTV shown has nine identified interface connections with the propellant depot. These are:

a. Fuel Cell Reactant (O_2).
b. LO_2 (for oxidizer fill and drain).
c. LH_2 (for propellant fill and drain).
d. Electrical connection for power and data.
e. GH_2 Thermodynamic Vent System (TVS) Vent.
f. GH_2 (fuel tank pressurization and venting).
g. GO_2 (oxidizer tank pressurization and venting.
h. Fuel Cell Reactant (H_2).
i. GO_2 TVS Vent.

This vehicle was assumed to use all electric actuation and autogenous (GO_2 and GH_2) gas pressurization from the engines to pressurize the propellant tanks during flight. Trade studies have shown this system to have a weight advantage over pneumatically pressurized systems for a space-based vehicle.

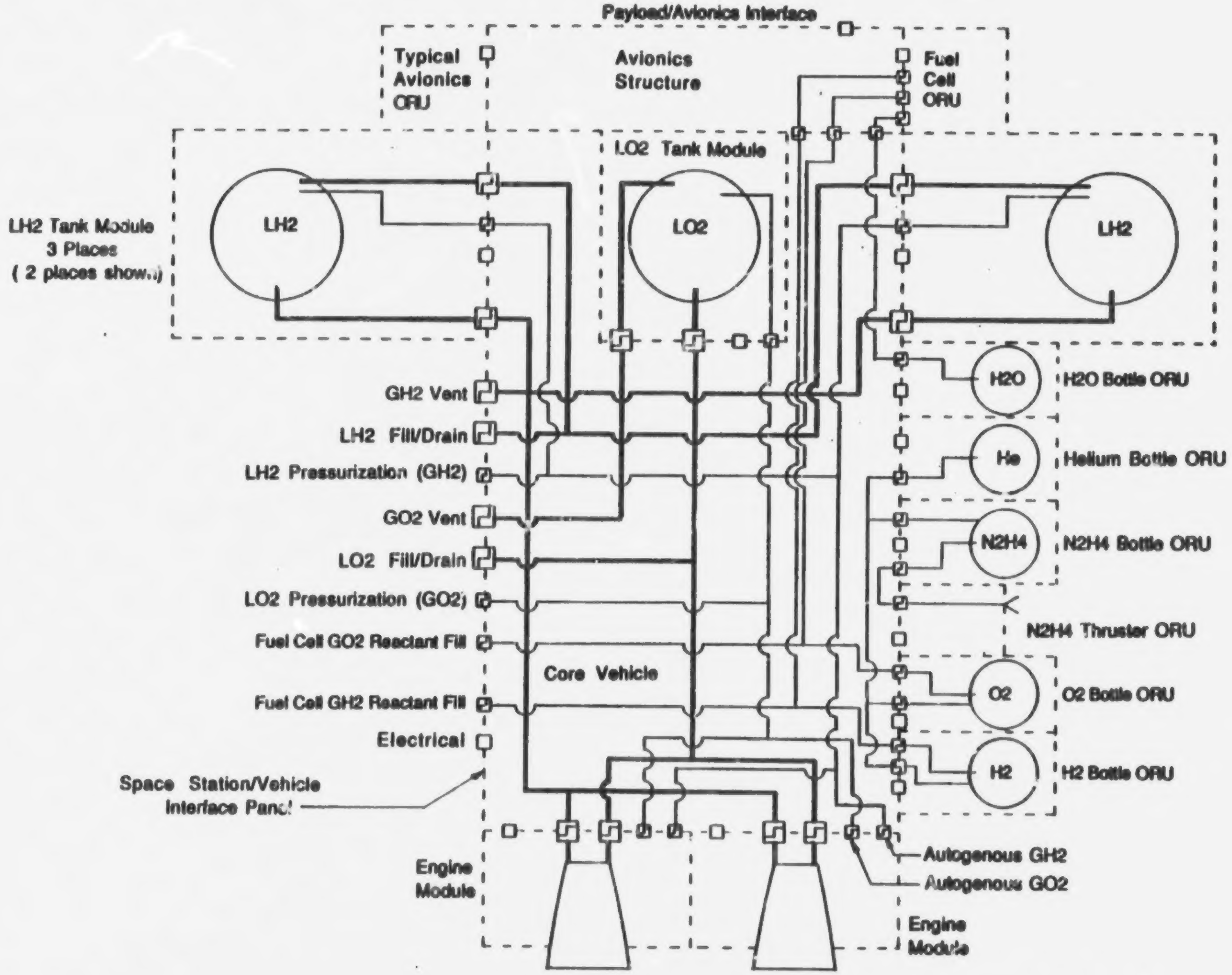

Figure 5-17. SBOTV Reference Configuration: Interface Schematic

Since N_2H_4 and He are used elsewhere on the Space Station, it was assumed that these bottles would be removed from the OTV, filled and reinstalled. Thus avoiding storage of these gases in two places.

The OTV would be brought to orbit in the Orbiter in five major sections, the core vehicle (including LO_2 tank, avionics, and engines), three LH_2 tanks, and the aerobrake. These sections would be assembled at the Space Station.

ORUs for the SBOTV reference configuration vary in weight from 25 pounds for the hydrazine thruster modules to 1000 pounds for the aerobrake structure or the thermal protection system (see Table 5-2).

The ORUs most likely to be replaced on a regular basis are:

a. Avionics Modules.

b. Payload Adapter Rings.

c. Multiple Payload Carrier.

d. Main Engine Assembly.

e. Aerobrake System.

f. RCS.

g. Helium Bottles.

h. H_2O Bottles.

i. N_2H_2 Bottles.

The average avionics module weighs approximately 100 pounds and measures 20 by 16 by 14, with the exception of the TDRSS avionics module which weighs about 56 pounds.

The aerobrake weights are based on a 44-foot-diameter aerobrake using a geotruss support structure and a 0.75-inch-thick fabric thermal protection system with a density of 8.5 lb/ft.[3]

The propellant tank module weights of 400 pounds assumed that the tanks were designed for 20 psia, any change in pressure would alter this weight.

The H_2O bottle would be removed after every mission to drain the water created by the fuel cells.

Prior to a mission the helium and N_2H_4 bottles would be removed from the OTV for filling or a line would be brought to the OTV to fill them, while the OTV was still in the hangar.

The SBOTV avionics system is composed of two parts, the individual avionics ORUs and the avionics core structure (see Figure 5-18).

The avionics ORUs allow the ability to change out individual avionics subsystems to accommodate mission-peculiar requirements or replace failed parts.

ORBITAL REPLACEMENT UNIT	SIZE (In.)	WEIGHT (lbs)
Large Avionics Module	28x16x14	107
Small Avionics Module	15x16x14	56
Payload Adapter Ring	50 dia. x 5	100
Multiple Payload Carrier	174 dia. x 25	725
Propellant Tank Module Assembly	138 dia.	400
RCS Thruster Module	10x10x10	25
Helium Storage Bottle Assembly	24 dia.	100
Main Engine Assembly	50 dia. x 52	400
RCS Tank Module Assembly	24 dia.	100
Aerobrake Structure Assembly	528 dia.	1000
Aerobrake Thermal Protection Sys.	528 dia.	1000
Avionics Core Structure	108 dia. x 24	450

* This data represents the typical subsystems used for estimating operations and timelines. These candidate solutions should be representative of the final OTV design.

272.363-119

Table 5-2. ORU Description/Weight Breakdown

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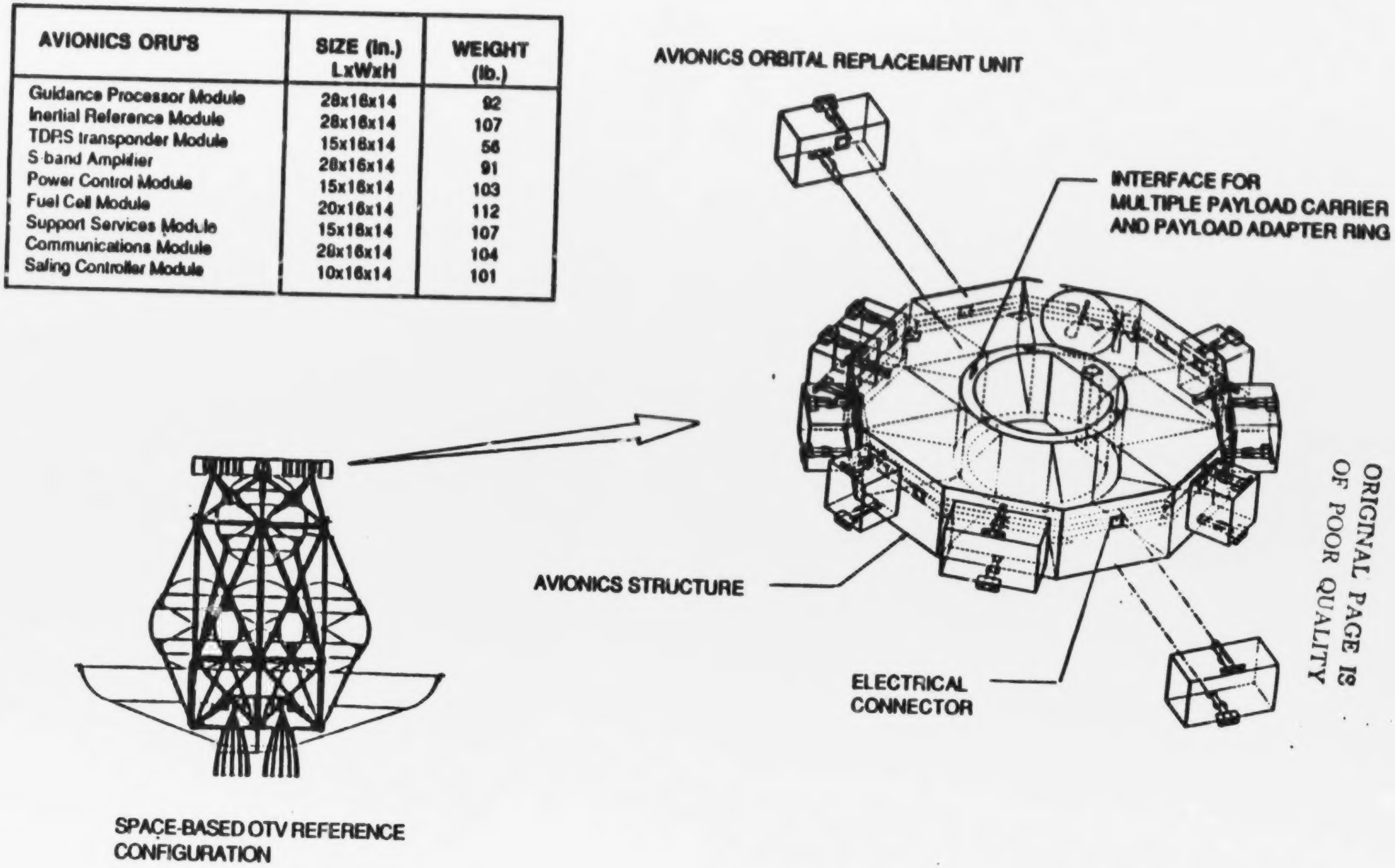

AVIONICS ORU'S	SIZE (In.) LxWxH	WEIGHT (lb.)
Guidance Processor Module	28x16x14	92
Inertial Reference Module	28x16x14	107
TDRS transponder Module	15x16x14	56
S-band Amplifier	28x16x14	91
Power Control Module	15x16x14	103
Fuel Cell Module	20x16x14	112
Support Services Module	15x16x14	107
Communications Module	28x16x14	104
Safing Controller Module	10x16x14	101

AVIONICS ORBITAL REPLACEMENT UNIT
INTERFACE FOR MULTIPLE PAYLOAD CARRIER AND PAYLOAD ADAPTER RING
AVIONICS STRUCTURE
ELECTRICAL CONNECTOR
SPACE-BASED OTV REFERENCE CONFIGURATION

272.353-120

Figure 5-18. OTV/Avionics Interfaces

There are three options for mounting the avionics modules. The first involves individually enclosing each subsystem, (as shown), and bolting them to the avionics structure in a manner similar to that used on the Multi Mission Spacecraft, (MMS). This has been successfully used during an EVA to repair the MMS, however, this would be a difficult operation for an RMS. The second concept is similar to the first but uses as manually engaged latch. This would simplify the replacement operation for both EVA and a RMS, however it would add weight to the system. The third option is to fully enclose all the avionics subsystems in one enclosure, but mount each subsystem on a removable rack, this would also be easier than the first option but would be the most complex.

The avionics ORUs would contain only an electrical interface with the core vehicle. The only exception may be the fuel cell, this may require fluid lines if the O_2, H_2, and H_2O tanks are not collocated with the fuel cell. The avionics may also require a fluid line to a radiator.

The avionics structure is removable to allow incorporating major block changes to the avionics system. The structure is mounted to the OTV core vehicle by three manually operated latches. These latches, (mounted on the bottom face of the structure), would be manually operated in order to avoid inadvertent release of the avionics system. The latches would be activated by an RMS or EVA astronaut by using a linkage attached to the outer side surface of the structure.

The OTV would require either a multiple-payload carrier with individual payload adapters for the multiple-payload deliveries or a single-payload adapter for the single-payload deliveries (see Figure 5-19).

The multiple-payload carrier/avionics interface, the payload adapter/multiple-payload carrier interface, and the payload adapter/avionics interface would use the same three-point manual latch system used to secure the avionics to the core structure. This would provide low weight, inadvertent release protection, and EVA or robotic operation.

The payload/payload adapter interface would use a three-point electrically operated latch to allow remote operation payload release. The latch selected for this would be similar to the berthing latch used in the shuttle Flight Support Structure, (FSS), which was used to hold the MMS during repairs. The latch design uses a single-failure-tolerant operation with a manual backup for emergency situations.

The reference SBOTV configuration has five propellant line interfaces that are routinely mated and demated. These are the OTV/propellant depot interface, the OTV/H_2O bottle interface, the OTV/N_2H_4 bottle interface, the OTV/He bottle interface, and the OTV/engine interface (see Figure 5-20). The first five interfaces will be mated twice per mission, (for tanking and detanking), and the OTV/engine panel will be demated and mated approximately once every 10 missions for routine engine replacement.

All other propellant interfaces will be mated or demated only during initial assembly or in a repair situation. These interfaces would probably use disconnects similar to the engine and depot interfaces to facilitate on-orbit maintenance.

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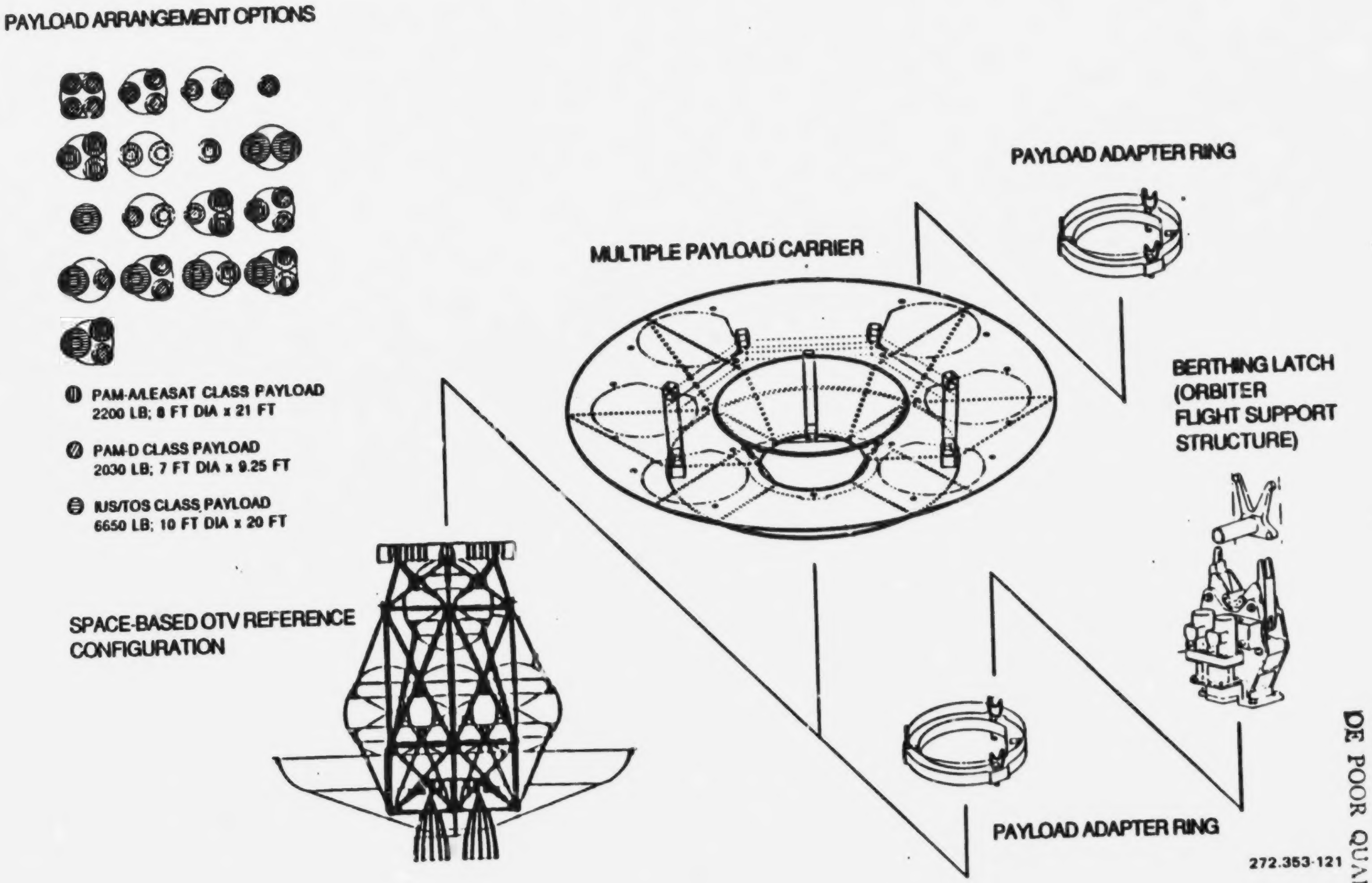

PAYLOAD ARRANGEMENT OPTIONS
① PAM-A/LEASAT CLASS PAYLOAD 2200 LB; 8 FT DIA x 21 FT
② PAM-D CLASS PAYLOAD 2030 LB; 7 FT DIA x 9.25 FT
③ IUS/TOS CLASS PAYLOAD 6650 LB; 10 FT DIA x 20 FT
SPACE-BASED OTV REFERENCE CONFIGURATION
MULTIPLE PAYLOAD CARRIER
PAYLOAD ADAPTER RING
BERTHING LATCH (ORBITER FLIGHT SUPPORT STRUCTURE)
PAYLOAD ADAPTER RING
272.353-121

Figure 5-19. OTV/Payload Interfaces

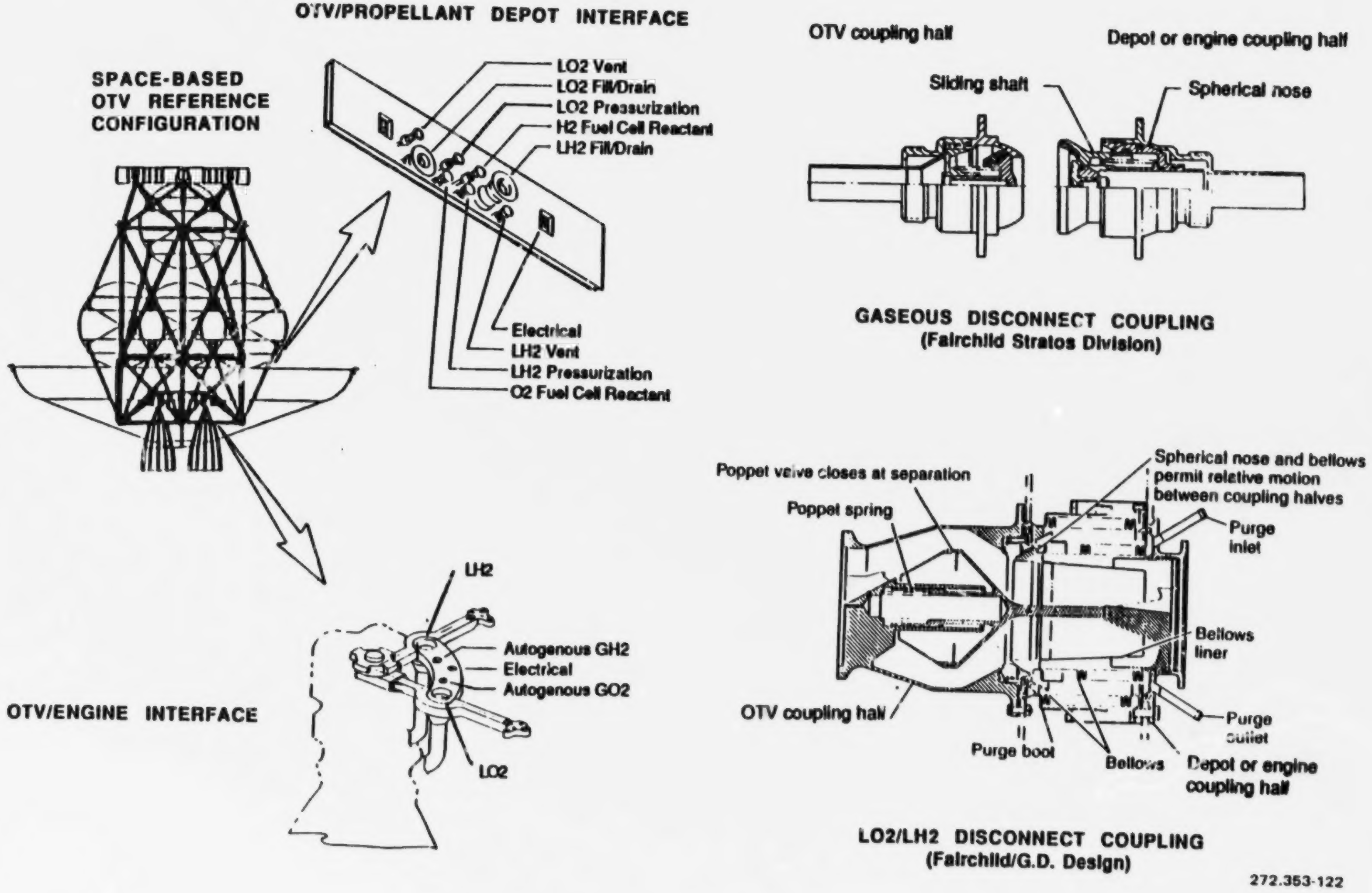


Figure 5-20. OTV Propellant Line Interfaces

All coupling similar to a model built by Fairchild is proposed for the gaseous disconnects. The coupling shown incorporates a spherical nose and sliding shaft on one side to accommodate lateral, axial, and radial misalignment between interface panels.

A cryogenic disconnect similar to that selected for the Shuttle/Centaur is proposed for the LO_2 and LH_2 couplings. This disconnect incorporates spherical ends and a bellows on one side to account for lateral, axial, and radial misalignment. The bellows half of the coupling includes a second bellows to capture any leakage and route it through purge lines so the leakage can be recaptured or safely vented.

The OTV propellant interface panel can be mated to the Space Station propellant interface panel in the following manner. The RMS would guide the OTV to the propellant boom using cameras mounted on either the boom or OTV propellant panels. When a sensor on the panels indicated a predetermined distance, two latches on the propellant boom panel would draw in the vehicle interface panel and lock it into position, which would simultaneously mate all the propellant and electrical connections.

The engine mounting concept is similar to a Pratt & Whitney concept. After the engine is attached to the OTV, the engine panel would be mated to a vehicle panel by utilizing manual latches on the engine panel that would engage the vehicle panel and draw the two together (approx. 1 inch of travel). The fluid and electrical connections would be similar to the OTV/propellant boom disconnects.

The latches on these panels would be similar to those on the payload adapters.

The aerobrake thermal blanket attachment interface consists of a standoff fitting on the aerobrake structural nodes and a 2-inch diameter. Titanium standoff tube on the thermal blanket (see Figure 5-21). Upon insertion of the tube in the fitting, the two units would lock together using an operation similar to a quick disconnect pin. Release of the parts would require gaining access to the back of the aerobrake to manually release the two. While installation and locking of the units would be fairly easy, the removal operation would be very cumbersome and requires more study. Dealing with a 44-foot diameter blanket is also a problem which requires more study.

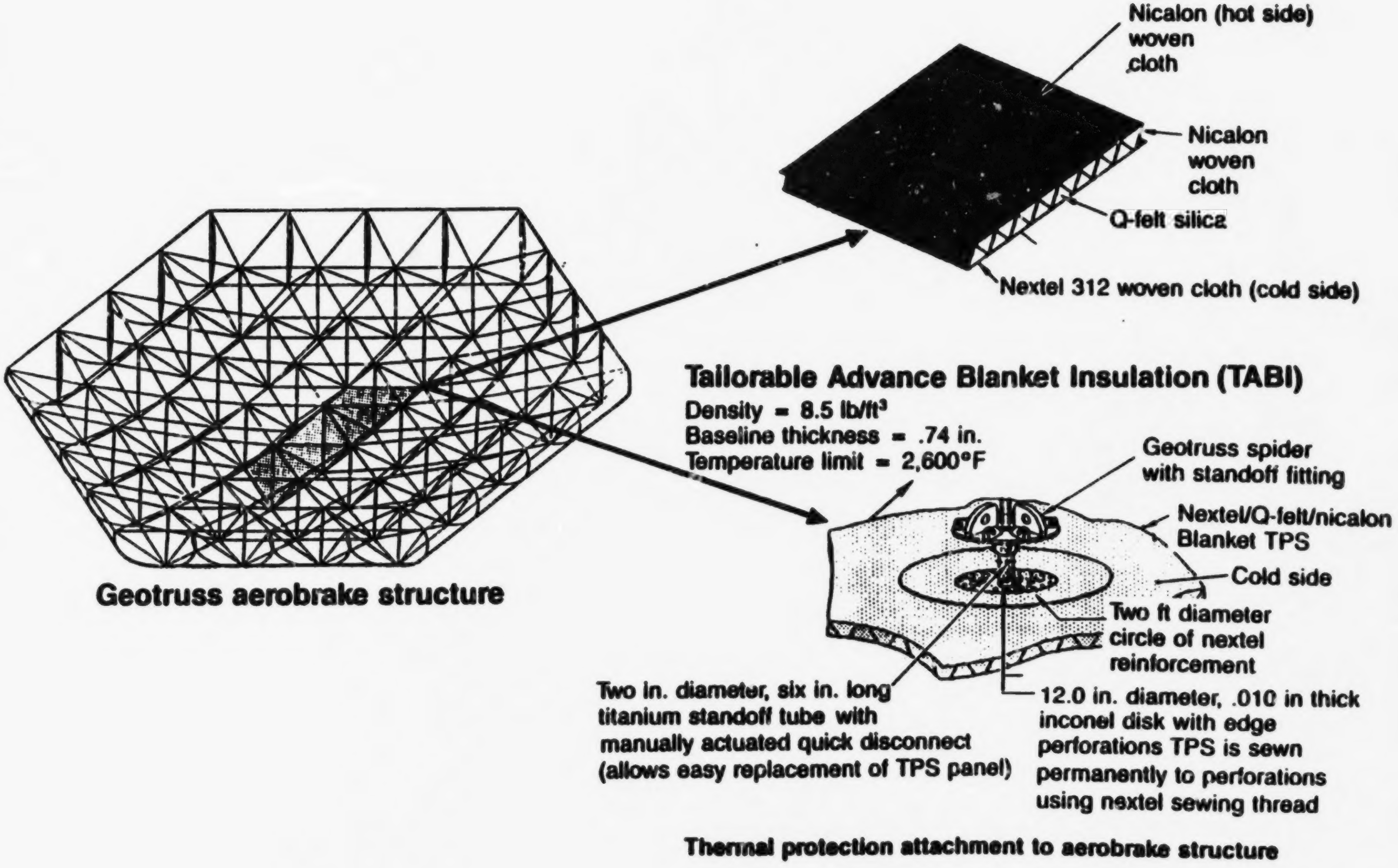

Nicalon (hot side) woven cloth
Nicalon woven cloth
Q-felt silica
Nextel 312 woven cloth (cold side)
Geotruss aerobrake structure
Tailorable Advance Blanket Insulation (TABI)
Density = 8.5 lb/ft³
Baseline thickness = .74 in.
Temperature limit = 2,600°F
Geotruss spider with standoff fitting
Nextel/Q-felt/nicalon Blanket TPS
Cold side
Two ft diameter circle of nextel reinforcement
Two in. diameter, six in. long titanium standoff tube with manually actuated quick disconnect (allows easy replacement of TPS panel)
12.0 in. diameter, .010 in thick inconel disk with edge perforations TPS is sewn permanently to perforations using nextel sewing thread
Thermal protection attachment to aerobrake structure

Figure 5-21. Aerobrake Thermal Protection Interface

SECTION 6

SPACE STATION DESIGN, SUPPORT, AND INTERFACE REQUIREMENT

Using the definition of the space-based support equipment, the operational maintenance, checkout and launch requirements, the definition of an SBOTV to meet the operational/interface requirements and the baseline Space Station functional and design concept, we performed a design requirements analysis to determine the accommodation needs from the Space Station to support the SBOTV.

In addition, operational and physical Space Station support and interface requirements in the following areas were identified:

a. Mechanical, fluid and electrical interfaces.

b. Center-of-gravity.

c. Spares storage.

d. Pressurized volume.

e. Propellant transfer and storage system.

f. Docking, berthing, and handling equipment.

g. Environmental protection.

h. Crew support requirements.

The support equipment, the crew support requirements, and SCARs needed on the initial station were defined.

The following ground rules and constraits were used in designing the OTV accommodations and handling equipment:

a. Power is provided by the Space Station.

b. Accommodations are located on dual-keel Space Station.

c. Accommodations must be designed for SBOTV Reference Configuration.

d. Mobile remote manipulator with EVA backup will be used for OTV servicing.

e. OTV accommodations (OTVA) are unpressurized.

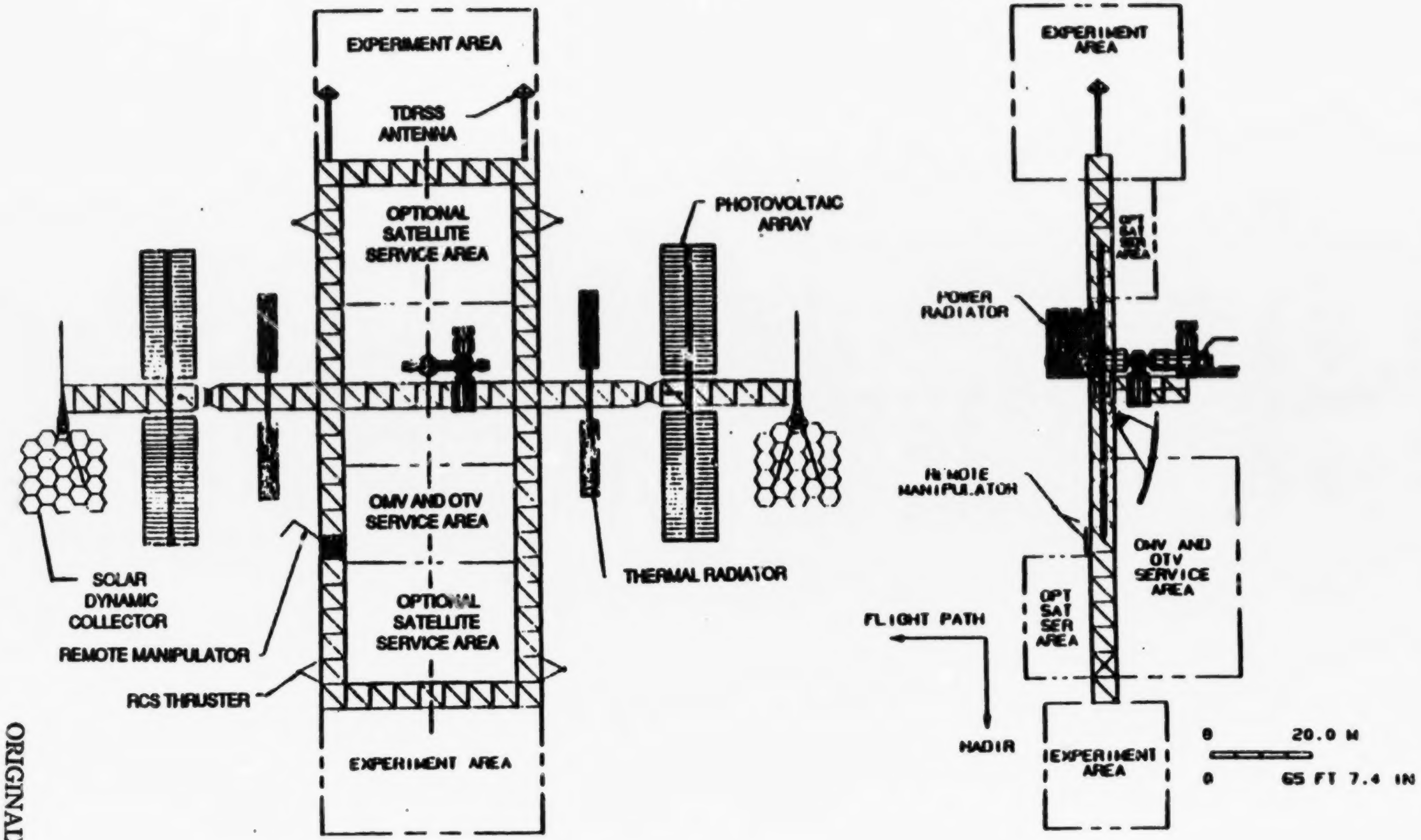
f. Long-term cryogenic storage facilities are onboard Space Station.

g. OTVA must accommodate two OTVs.

h. OTVA will provide micrometeoroid/debris protection for OTV and related equipment.

6.1 BASELINE SPACE STATION

The Space Station guidelines present in JSC 30000 SEC. 3 Rev. B were used as a guide for designing the OTV accommodations. Figure 6-1 shows the baseline Space Station concept.



JSC 30000 SEC. 3 REV. B
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Figure 6-1. Baseline Space Station Concept

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6.2 SBOTV MAINTENANCE FACILITY/SUPPORT EQUIPMENT REQUIREMENTS.

The equipment required to outfit the OTV hangar facility is as follows:

a. Maintenance and storage facility.
   1. Main truss support structure (similar to Space Station).
   2. OTV internal hangar berthing fixture for two OTVs (rotary).
   3. Electrical interconnects between internal berthing interface, OTV control equipment, and power source.
   4. OTV external berthing fixture (for propellant loading and staging).
   5. Electrical interconnects between external berthing interface, OTV control equipment and power source.
   6. Fluid lines from external berthing quick disconnect panel to propellant storage/transfer control interface.
   7. Support structures for hangar and equipment.
   8. TV, lighting, communications, and propellant leak detection installation.
   9. RMS installation including rails, local TV, lights, and tool adapter.
   10. Electrical interconnects from RMS to facility control equipment.
   11. Tools and spares storage provisions.
   12. EVA foot constraints/handholds/control panel.
   13. Protective covering (micrometeoroid and space debris).
   14. Hangar protective cover support structure.
   15. Lightweight screen for hangar opening.
   16. Possible antenna installations.

b. Tools
   1. EVA/RMS maintenance tools.
   2. RMS astronaut work station.

c. Spares storage
   1. Holding fixtures for tanksets.
   2. Holding fixtures for avionics ORU's ACS module, engines and aerobrake.
   3. Holding fixtures for EVA/RMS maintenance tools.
   4. Holding fixtures for OTV payload and manned GEO crew module.

d. Propellant storage
   1. Main support structure.
   2. Hydrogen and oxygen storage tank.

  3. Propellant acquisition, conditioning and gauging.
  4. Fluid lines from tanks to control interface.
  5. Refrigeration unit and plumbing or boil-off module.
  6. Electrical interface between control unit, refrigeration unit or boil-off and power.
  7. Protective covering (micrometeoroid and space debris).
  8. Heat rejection.
  9. Emergency non-propulsive gaseous vent system.

e. Control station and maintenance are (pressurized module)
  1. Rendezvous, Docking, and berthing control.
  2. OTV direct control through berthing fixtures.
  3. Hangar equipment control.
  4. Propellant facility control.
  5. Airlock for EVA operations.
  6. Communications and data links.
  7. Tools, maintenance, and checkout equipment and maintenance area.

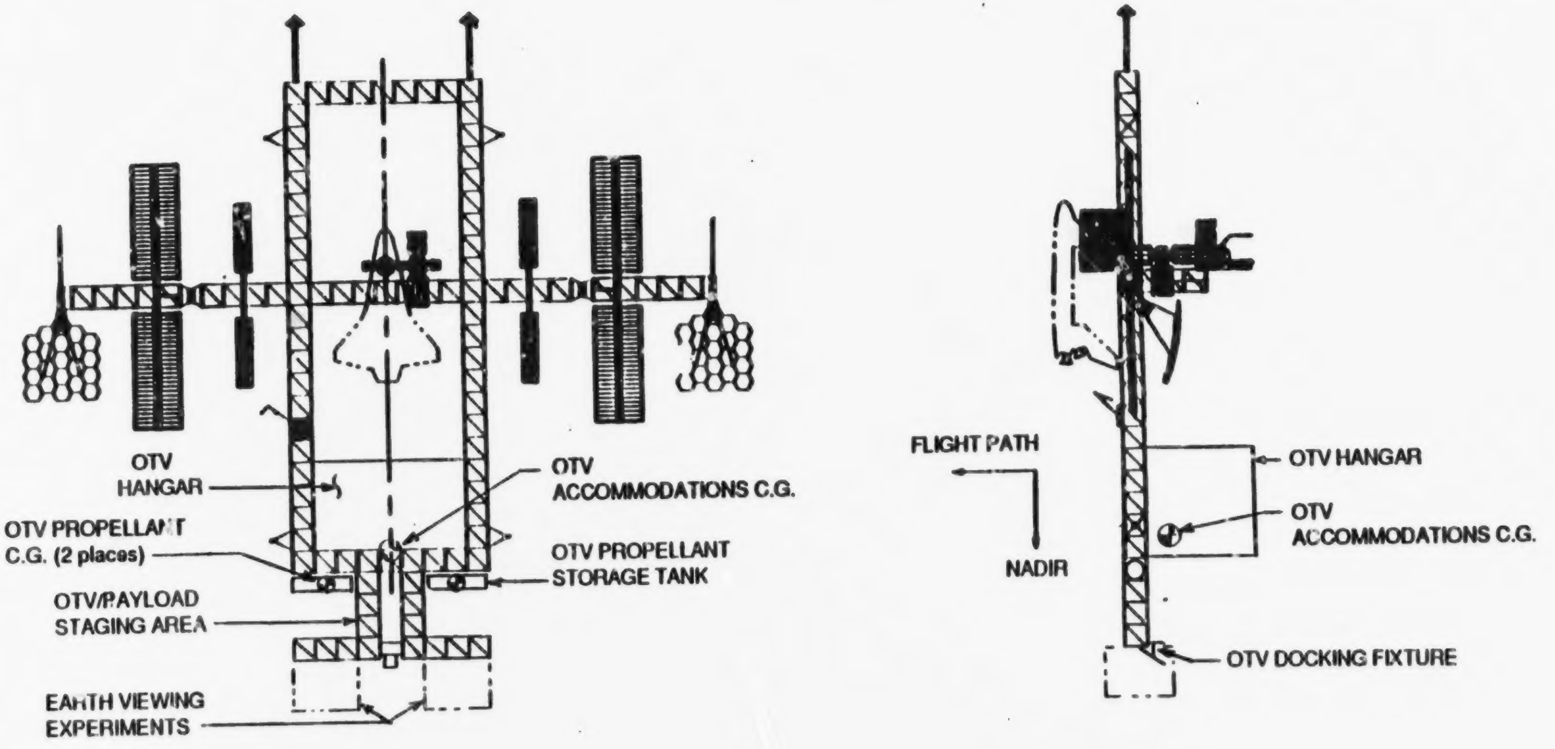
6.3 SPACE STATION OTV ACCOMMODATIONS

The OTV facility was located on the bottom leeward side of the dual-keel Space Station (see Figure 6-2). This location was chosen based on the constraints of JSC 30000, Section 3 Revision B. Placing the hangar in this position allows the Orbiter to dock at a manned module on the windward side of the station and maintain adequate clearance with the hangar. This position also allows docking of the OTV at a safe distance from manned modules. The exact location of the hangar down from the manned modules will depend on the clearance required between the hangar and the docked Orbiter tail.

The LTCSF (OTV propellant storage tanks) tanks are positioned at the bottom of the hangar facility in a horizontal position. This minimizes the OTV propellant fluid line lengths and aids in propellant acquisition.

An OTV staging propellant loading boom is located directly beneath the hangar to provide easy access into and out of the hangar, (the hangar has an open bottom face), and provide a launch and retrieval point away from critical station elements. The OTV propellant resupply tanker also docks on this same loading boom.

The front and side views of an OTV hangar on the dual-keel Space Station are shown in Figure 6-3. This facility was designed to accommodate the NASA reference configuration SBOTV, and meet the requirements of the Revision 8 OTV mission model. The frame of this facility is composed of the same 5-meter trusses used on the Space Station to allow easy RMS access into and out of the hangar. In addition, the bottom of the hangar is open, since no micrometeoroid or debris hazard is expected from this direction.



WEIGHT SUMMARY (lbs.)*

OTV Accommodations	= 92000	OMV Dry	= 3000
OTV Propellants	= 200000	Payload	= 20000
OMV Propellants	= 14000		
OTV Dry	= 9070	TOTAL	= 338070

* Required to meet all NASA revision 8 missions

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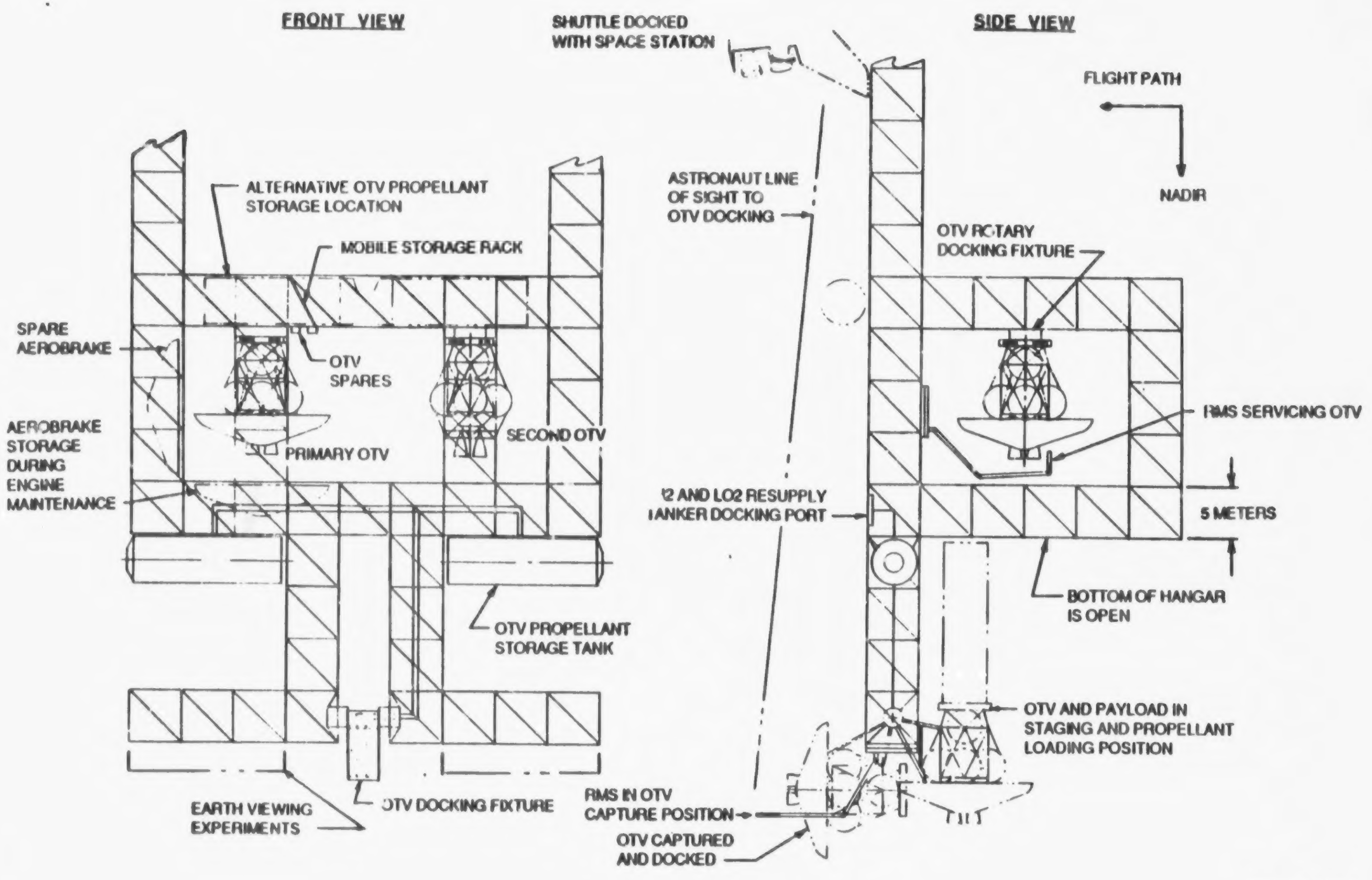
Figure 6-2. Space Station OTV Accommodations (for Space-Based OTV Reference Configuration


FRONT VIEW
ALTERNATIVE OTV PROPELLANT STORAGE LOCATION
MOBILE STORAGE RACK
SPARE AEROBRAKE
OTV SPARES
AEROBRAKE STORAGE DURING ENGINE MAINTENANCE
PRIMARY OTV
SECOND OTV
OTV PROPELLANT STORAGE TANK
EARTH VIEWING EXPERIMENTS
OTV DOCKING FIXTURE
SHUTTLE DOCKED WITH SPACE STATION
ASTRONAUT LINE OF SIGHT TO OTV DOCKING
12 AND LO2 RESUPPLY TANKER DOCKING PORT
RMS IN OTV CAPTURE POSITION
OTV CAPTURED AND DOCKED
SIDE VIEW
FLIGHT PATH
NADIR
OTV ROTARY DOCKING FIXTURE
RMS SERVICING OTV
5 METERS
BOTTOM OF HANGAR IS OPEN
OTV AND PAYLOAD IN STAGING AND PROPELLANT LOADING POSITION

272.353-126-1

Figure 6-3. Space Station OTV Hangar Facility (for Space-Based OTV Reference Configuration)

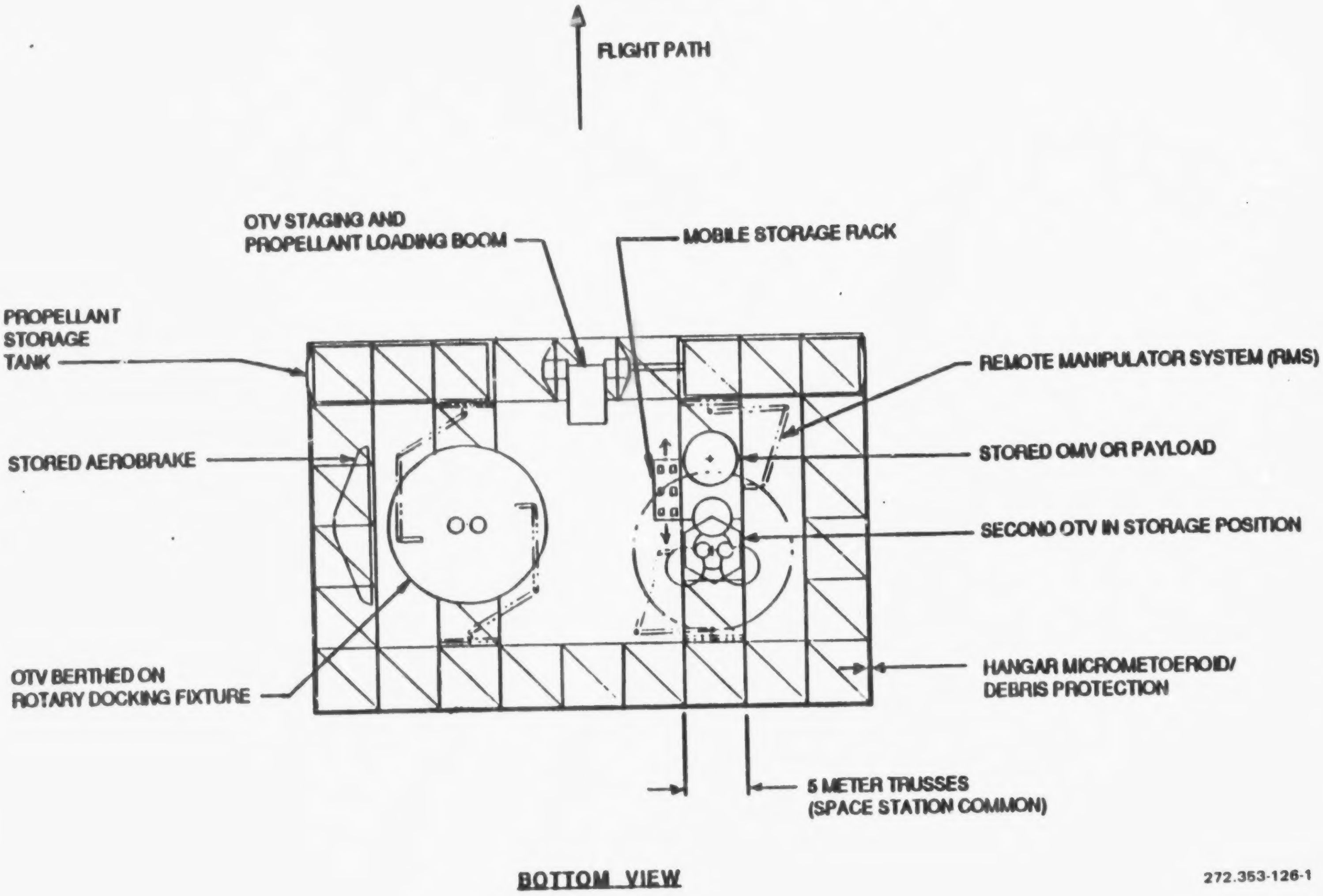

FLIGHT PATH
OTV STAGING AND PROPELLANT LOADING BOOM
MOBILE STORAGE RACK
PROPELLANT STORAGE TANK
REMOTE MANIPULATOR SYSTEM (RMS)
STORED AEROBRAKE
STORED OMV OR PAYLOAD
SECOND OTV IN STORAGE POSITION
OTV BERTHED ON ROTARY DOCKING FIXTURE
HANGAR MICROMETEOROID/ DEBRIS PROTECTION
5 METER TRUSSES (SPACE STATION COMMON)
BOTTOM VIEW
272.353-126-1

Figure 6-3. Space Station OTV Hangar Facility (for Space-Based OTV Reference Configuration), Contd

The hangar is capable of accommodating two OTVs and a 50-foot long payload or OMV. An OTV is shown docked inside the hangar on a rotary docking fixture, which mates with the OTVs payload docking interface. This allows 360 degree access to all the OTV components and permits rotation of the OTV during servicing, which allows an RMS to do almost all OTV servicing from one position.

The OTV payload staging and propellant loading boom is location directly below the hangar which allows the OTV to be captured, launched, and moved into and out of the hangar with a minimum amount of motion and also eliminate RMS plane changes from one side of a boom to the other, while carrying the OTV. This boom is designed to hold the OTV and permit the mating of a 50 foot-long payload. The boom is also used to dock the OTV propellant resupply tanker.

The bottom view of the hangar (see Figure 6-4) shows the location of the primary OTV, a second OTV, and the payload or OMV. The primary OTV is shown in a position that allows two RMSs on opposite sides of the hangar to service it. The second OTV is shown in a storage location that permits it to have its aerobrake attached, however, only one RMS can service the vehicle in this position of a payload is stored on the docking fixture shown. Also shown in this figure is a mobile tool and spares storage rack that can move tools and spares to the work area to ease the workload of the RMS.

6.4 OTV STORAGE/MAINTENANCE FACILITY INTERFACES

6.4.1 FLUID INTERFACES. The OTV hangar facility fluid interfaces (see Figure 6-4) are between the hangar and the following items:

a. LTCSF (2 places).

b. Space Station.

c. OTV propellant loading and staging boom.

Only one LTCSF facility is illustrated, the second facility is identical to the one shown and is simply teed into the hangar side of the fluid lines shown routed to the LTCSF.

The fluid interface between the hangar and Space Station if the NH_3 coolant required to dissipate the heat from the hangar electronics and the LTCSF reliquefier.

The heat is transferred from the hangar and LTCSF coolant lines to the Space Station NH_3 coolant line via a heat exchanger located in the hangar power and data management and distribution control center.

The OTV propellant loading and staging boom is used to fill and drain propellants form the OTV and also to unload propellants from the OTV propellant resupply tanker.

6.4.2 ELECTRICAL INTERFACE. The major OTV hangar facility electrical interfaces (see Figure 6-5) are between the hangar and the following items:

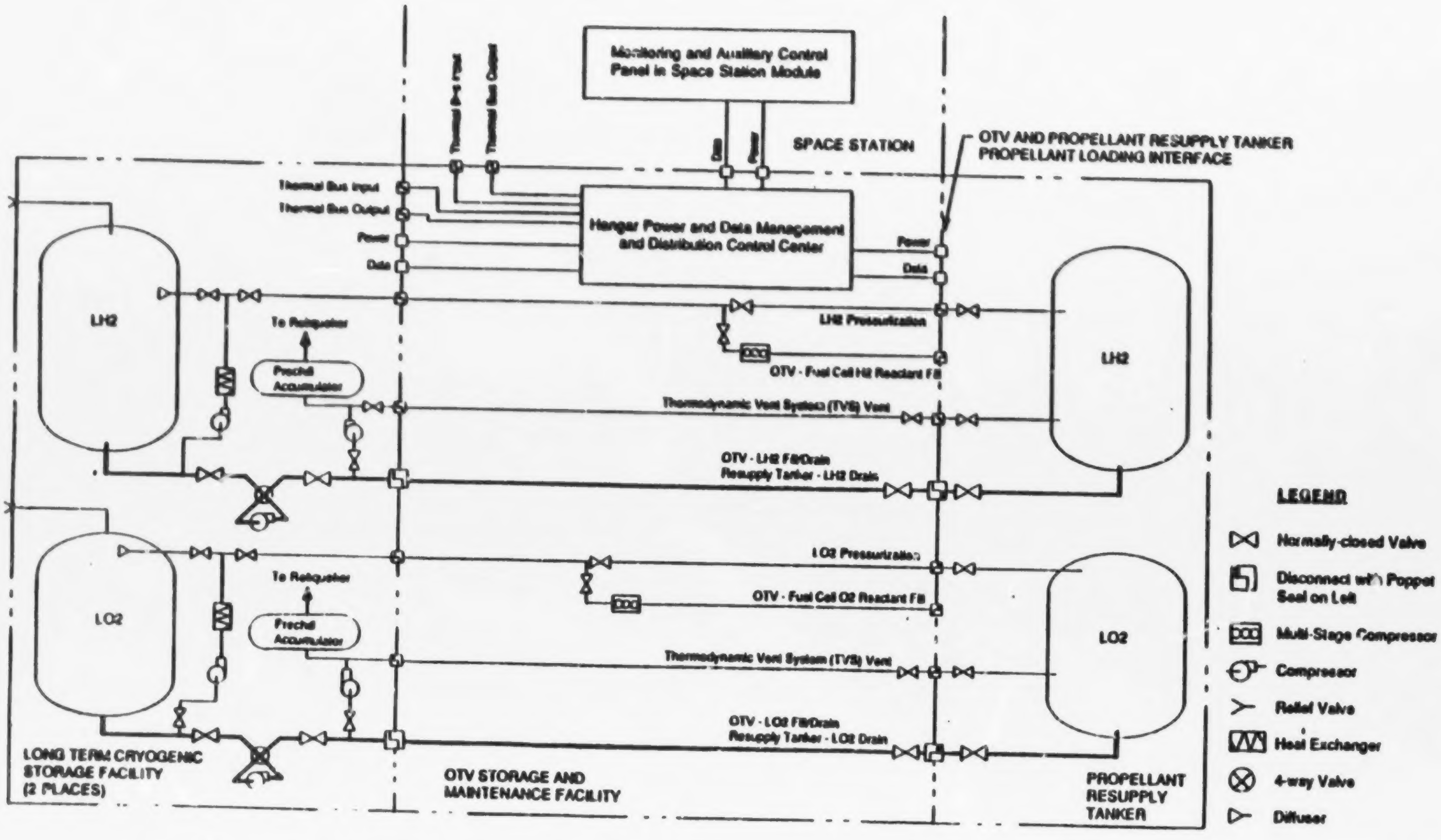

Monitoring and Auxiliary Control Panel in Space Station Module
Thermal Bus Input
Thermal Bus Output
Data
Power
SPACE STATION
OTV AND PROPELLANT RESUPPLY TANKER PROPELLANT LOADING INTERFACE
Thermal Bus Input
Thermal Bus Output
Power
Data
Hangar Power and Data Management and Distribution Control Center
Power
Data
LH2
To Reliquefier
Prechill Accumulator
LH2 Pressurization
OTV - Fuel Cell H2 Reactant Fill
LH2
Thermodynamic Vent System (TVS) Vent
OTV - LH2 Fill/Drain
Resupply Tanker - LH2 Drain
LO2
To Reliquefier
Prechill Accumulator
LO2 Pressurization
OTV - Fuel Cell O2 Reactant Fill
LO2
Thermodynamic Vent System (TVS) Vent
OTV - LO2 Fill/Drain
Resupply Tanker - LO2 Drain
LONG TERM CRYOGENIC STORAGE FACILITY (2 PLACES)
OTV STORAGE AND MAINTENANCE FACILITY
PROPELLANT RESUPPLY TANKER
LEGEND
Normally-closed Valve
Disconnect with Poppet Seal on Left
Multi-Stage Compressor
Compressor
Relief Valve
Heat Exchanger
4-way Valve
Diffuser

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Figure 6-4. OTV Storage/Maintenance Facility Fluid System Interface Schematic

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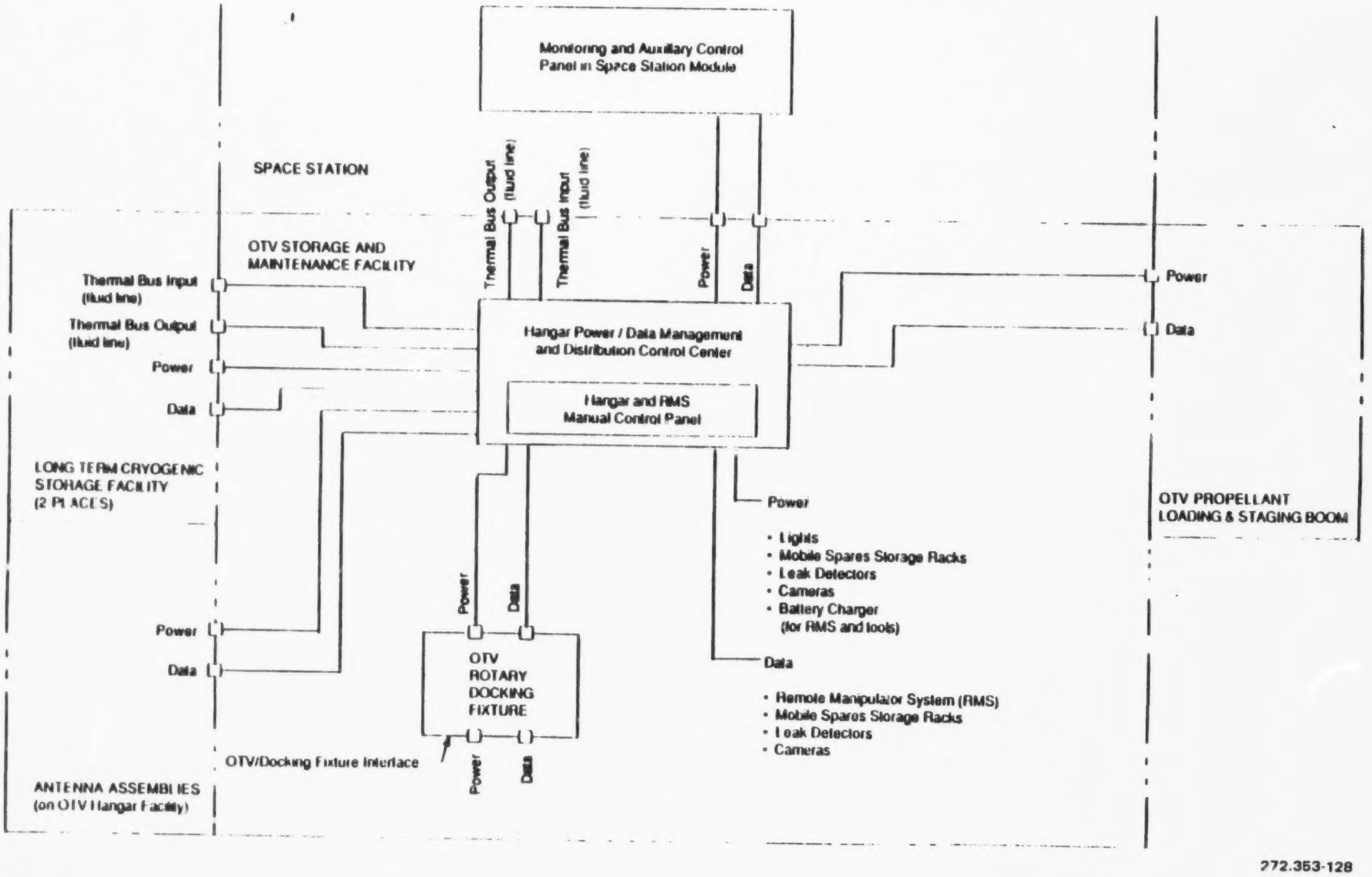
Monitoring and Auxiliary Control Panel in Space Station Module
SPACE STATION
OTV STORAGE AND MAINTENANCE FACILITY
Thermal Bus Output (fluid line)
Thermal Bus Input (fluid line)
Power
Data
Thermal Bus Input (fluid line)
Thermal Bus Output (fluid line)
Power
Data
Hangar Power / Data Management and Distribution Control Center
Hangar and RMS Manual Control Panel
Power
Data
OTV PROPELLANT LOADING & STAGING BOOM
LONG TERM CRYOGENIC STORAGE FACILITY (2 PLACES)
Power
Data
Power
Data
OTV ROTARY DOCKING FIXTURE
Power
Data
OTV/Docking Fixture Interface
ANTENNA ASSEMBLIES (on OTV Hangar Facility)
Power
· Lights
· Mobile Spares Storage Racks
· Leak Detectors
· Cameras
· Battery Charger (for RMS and tools)
Data
· Remote Manipulator System (RMS)
· Mobile Spares Storage Racks
· Leak Detectors
· Cameras
272.353-128

Figure 6-5. OTV Storage/Maintenance Facility Electrical System Interface Schematic

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a. LTCSF (2 places).

b. Antenna assemblies and experiments (TBD places).

c. OTV docked on the propellant loading and staging boom.

d. Propellant resupply tanker docked on the propellant loading the staging boom.

e. OTV docked on the internal hangar docking fixture.

f. Miscellaneous assemblies in the hangar.

OTV hangar power (approximately TBD Watts) will be provided by the Space Station and distributed by the hangar power/data management and distribution control center. This center can be controlled by astronauts in a Space Station module or by EVA at the control panel in the hangar.

The LTCSF tanks (with active cooling) will require approximately 4.2 Watts peak. The rest of the power will be fairly evenly divided among the other units of the hangar.

This concept also assumes that the RMSs servicing the OTV will be battery operated and periodically recharged in the OTV hangar facility.

6.5 OTV HANDLING AND STORAGE EQUIPMENT

6.5.1 HANGAR CONTROL CONSOLE AND OTV ROTARY DOCKING FIXTURE. The OTV hangar facility has an EVA control console (see Figure 6-6) to monitor hangar operations during EVA required servicing of the OTV. Also, an astronaut/RMS workstation would be located next to the console to allow the astronaut to be picked up by an RMS to manually service the OTV.

The OTV will be docked to a rotary docking fixture (see Figure 6-7), which will mate with the forward end of the OTV avionics ring. This will provide servicing access to all OTV components, and allow the vehicle to be rotated 360 degrees, thus minimizing RMS movement around the vehicle.

A mobile storage rack was chosen to store OTV spares and provide an efficient means of delivering parts to where they are needed (see Figure 6-6). The mobile storage rack would reduce OTV repair time by delivering to whichever side of the hangar the RMS was working on, thus the RMS would never have to leave its work area to obtain a part.

The mobile storage rack is located at the top of the hangar to avoid any interference with the RMS.

The mobile storage rack can also be utilized as a means for an astronaut to travel around the hangar.

This storage rack may also be fixed depending on the hangar with and RMS reach.

6.5.2 OTV SERVICING TOOL REQUIREMENTS. The Universal Servicing Tool (UST) (see Figure 6-7) will be used to perform all the currently identified servicing of the OTV. Special tools required for individual tasks can be plugged into the UST enabling the UST to adapt to the required operation.

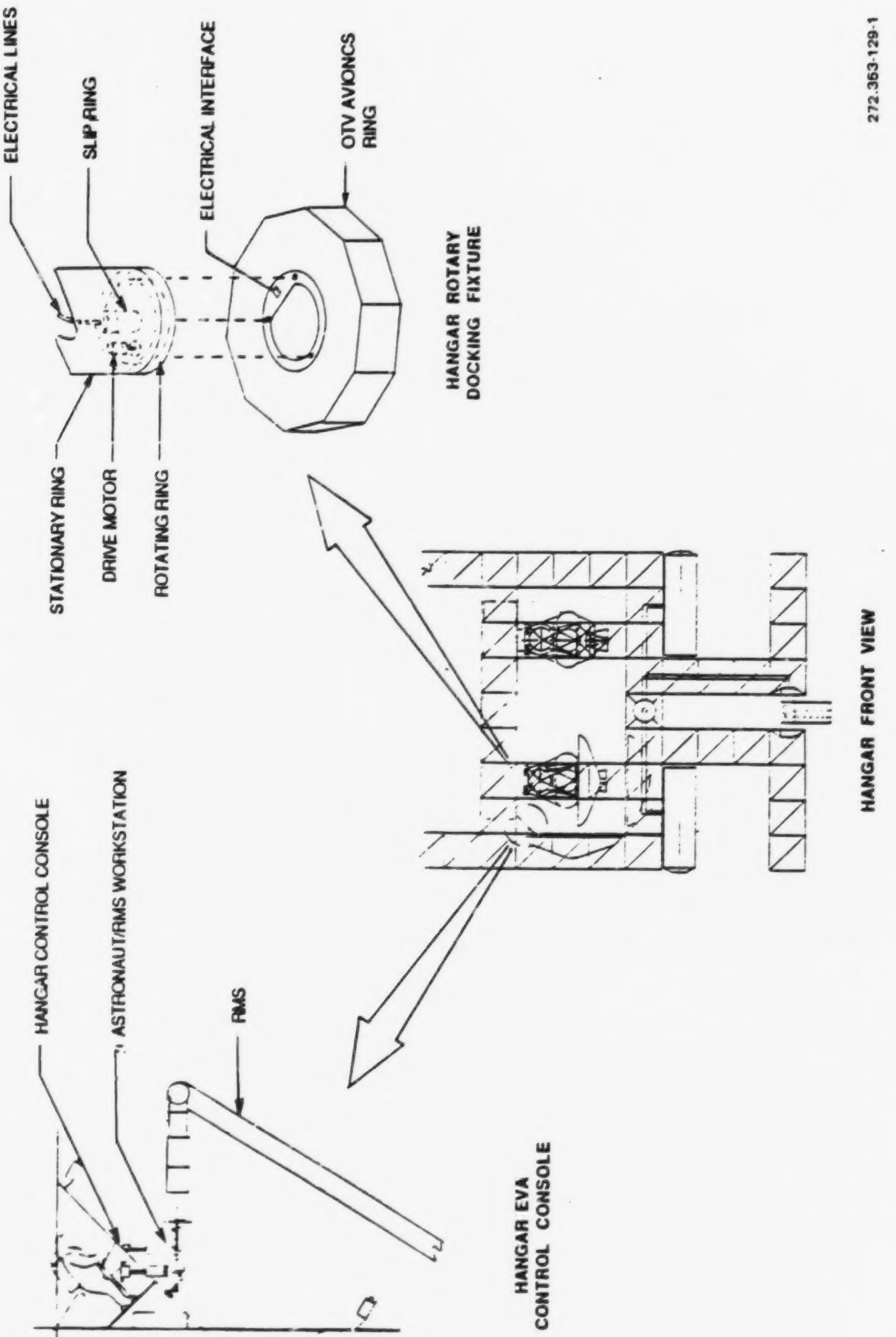


Figure 6-6. OTV Handling and Storage Equipment

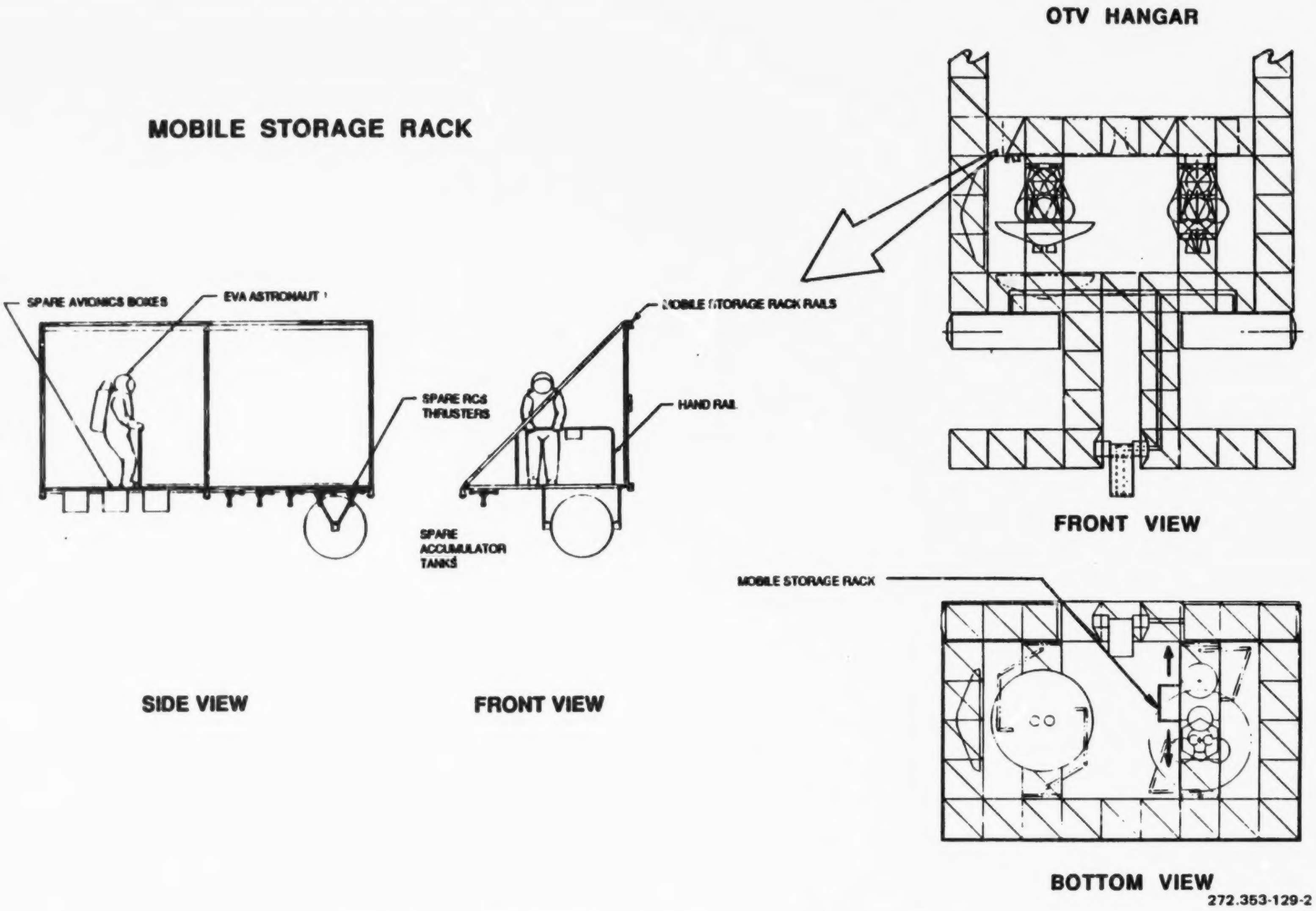
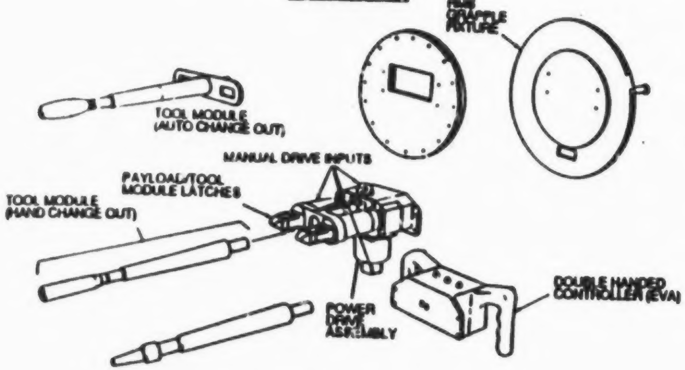
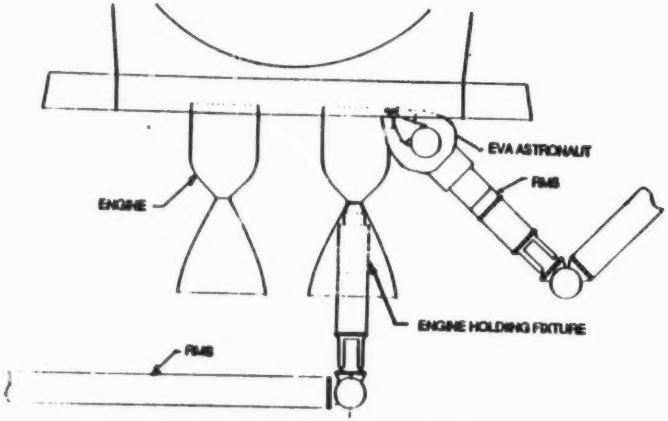


Figure 6-6. OTV Handling and Storage Equipment, Contd

TOOLS


RMS GRAPPLE FIXTURE
TOOL MODULE (AUTO CHANGE OUT)
MANUAL DRIVE INPUTS
PAYLOAD/TOOL MODULE LATCHES
TOOL MODULE (HAND CHANGE OUT)
DOUBLE HANDED CONTROLLER (EVA)
POWER DRIVE ASSEMBLY

UNIVERSAL SERVICING TOOL



ENGINE HOLDING FIXTURE

FUNCTION

- AVIONICS REMOVAL/REPLACEMENT
- PAYLOAD ADAPTER REMOVAL/REPLACEMENT
- GAS BOTTLE AND PROPELLANT TANK REMOVAL/REPLACEMENT

- HOLD ENGINE DURING REMOVAL/REPLACEMENT

272.353-130

Figure 6-7. OTV Servicing Tool Requirements

The engine is the only identified OTV component that will require a special holding fixture to remove/replace it. This tool is planned to be inserted into the throat of the engine to hold it during replacement.

6.5.3 RMS REQUIREMENTS. A maximum of two hangar RMSs will be required to perform all the OTV maintenance requirements (see Table 6-1). The station RMS will be required to dock and launch the OTV. The station RMS will also be used to bring the OTV payload from its docking facility (outside the OTV hangar) to the OTV staging area.

6.6 SPACE STATION OTV OPERATION COMMAND CENTER

Figure 6-8 shows a conception of the OTV hangar control center (located in a pressurized module) with estimates of the required components, weights, and volume.

This center is set up to monitor and control two RMSs in the OTV hangar facility.

6.7 OTV TURNAROUND OPERATIONS CREW REQUIREMENTS

The number of crewman required for various phases of OTV turnaround operations are as follows:

a. OTV rendezvous, capture, and launch.
   1. 1 crewman for line-of-sight observation (pressurized module).
   2. 1 crewman operating the multipurpose applications console (MPAC).
   3. 23 ground controllers (monitoring only).

b. OTV maintenance operations performed with RMS.
   1. 1 crewman operating the MPAC and RMS.
   2. 1 crewman operating the second RMS from the MPAC (when 2 RMSs required).
   3. 23 ground controllers (monitoring only).

c. OTV maintenance operation performed with EVA.
   1. 2 EVA astronauts.
   2. 1 crewman operating MPAC.
   3. 23 ground controllers (monitoring only).

d. OTV flight operations: 1 crewman operating MPAC while OTV is within 37 km of Space Station.

6.8 SPACE STATION SCAR REQUIREMENTS FOR OTV ACCOMMODATION

The dual-keel Space Station SCARs required to provide for the pressurized and unpressurized components of the OTV hangar facility are given in Table 6-2.

TASK	OPERATION	RMS REQUIREMENTS	
		HANGAR RMS	STATION RMS
Aerobrake R/R	Teleoperations	2	
Aerobrake TPS R/R	EVA	2	
Engine R/R	Teleoperations	2	
Tankset R/R	Teleoperations	2	
Avionics Changeout	Teleoperations	1	
RCS R/R	Teleoperations	1	
Initial OTV Delivery & Assembly	Teleoperations	2	1
OTV Rendezvous & Berthing	Teleoperations	1	1
Payload Integration	Teleoperations	1	1
Prelaunch-Launch	Teleoperations		1
Propellant Facility Delivery & Assembly	Teleoperations	1	1
Propellant Facility Maintenance	Teleoperations & EVA	2	
Hangar Maintenance	Teleoperations & EVA	1	
Hangar Assembly	Teleoperations & EVA	1	1

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Table 6-1. RMS Requirements

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PRESSURIZED VOLUME REQUIREMENTS	100 cu. ft.
PRESSURIZED WEIGHTS	**330 lb.**
2 RMS CONTROLLERS	120 lb.
8 SMALL TV MONITORS	80 lb.
2 LARGE TV MONITORS	60 lb.
ELECTRONICS	70 lb.

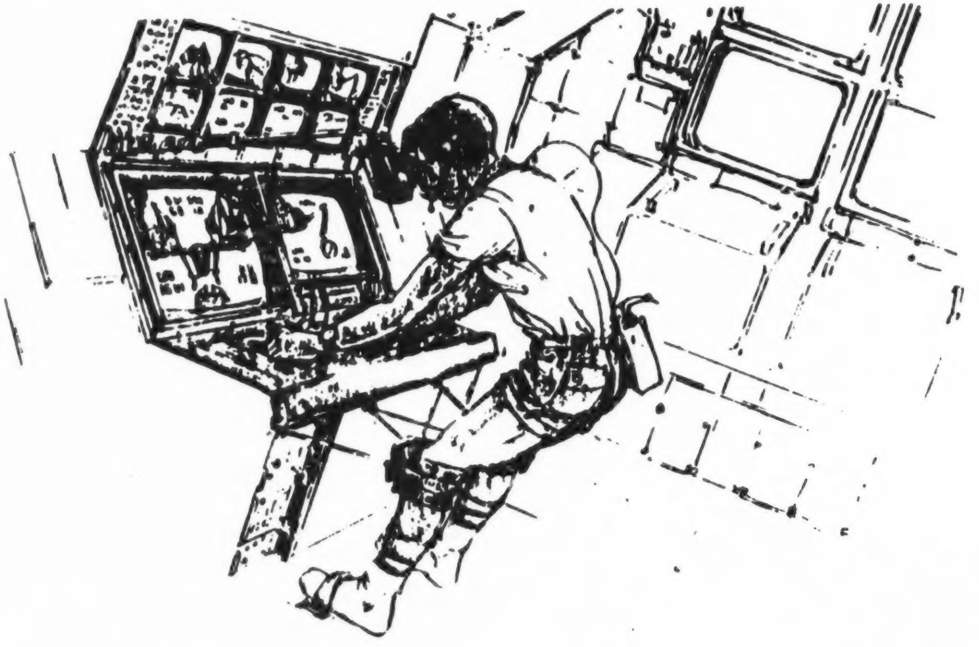

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Figure 6-8. Space Station OTV Operations Command Center

EQUIPMENT	QUANTITY	MASS (lb.)	CHARACTERISTICS
Electric Power Distribution Interface Panel	1	30[*]	TBD kw Peak 440 VAC; 20 kHz[*]
Multi-Purpose Applications Console Interface Panel in Pressurized Module	1	5	TBD kw Peak 440 VAC; 20 kHz[*]
Communications & Tracking Interface Panel - Video	1	20[*]	 3 mbps[*]
Thermal Control Bus	1	TBD	TBD
Structural Mounting for Interface Panels	TBD	TBD	Supports interface panels between SS and OTVA.
Cable Hangars	TBD	TBD	Supports cables from SS to OTVA
Truss Attachments	TBD Corner Truss Nodes	TBD	Required for supporting 4 main OTVA support trusses and 2 lower booms.
Data Management Interface Panel - OTVA Monitoring - OTV Monitoring - OTV and OTVA Commands	1	20[*]	 6 kbps[*] 1 kbps[*] 1 kbps[*]

[*] Interface characteristics obtained from SS-SPEC-0008 REV. 6/30/86

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Table 6-2. Space Station SCAR Equipment for OTV Accommodations

A pressurized module must be SCARed for the hangar control console, and provisions must be made for the data and command lines for the module to the hangar.

Lines must be routed from the Space Station power management and distribution center to provide power to the hangar and allow waste heat to be rejected.

The Space Station truss nodes in the hangar vicinity must be designed to permit attachment of the hangar support structure.

SECTION 7

SUPPORT EQUIPMENT DEVELOPMENT SCHEDULE AND TURNAROUND OPERATIONS COSTS

This section presents the support equipment development schedule, development costs and the manpower operations costs at the Space Station.

7.1 DEVELOPMENT SCHEDULE

Figure 7-1 shows the overall design and development schedule for the OTV accommodations/support equipment from operational acceptance through several launches to the Space Station and when the expected IOC will occur. The development schedules for the Space Station and OTV are also shown to see how the main elements of the program are related and integrated. The Space Station's first launch is scheduled to occur in 1994. Man-tended operations will start in 1995, and the Phase I IOC will occur in 1996. The Phase II buildup will be completed in 1999 which allows the accommodations buildup to begin.

The expected development of the SBOTV is shown from the pre-phase A studies, which are going on at the present time to the IOC in 2001. It turns out that this schedule directly parallels the development schedule of the OTV accommodations/support hardware. This includes ground, Shuttle/ELV, and Space Station activities. The technology development schedule is expanded on the following charts.

Figure 7-2 shows the development schedule for the ground operations technology. The areas of technology development are called out on the chart.

Applications analysis will take place starting in 1989 and the selection of applications for testing will take place in 1991. Testing will continue through 1994 up to the start of the OTV and accommodations Phase C/D.

Figure 7-3 shows the development schedule for one of the areas of space operations technology, namely cryogenic fluid transfer, long-term storage, and fluid management.

An experiment launched on an ELV has been proposed. The launch is scheduled for early in 1994 and the experiment is designed to have an operating life on orbit of 2 years. This data will be available by the CDR for the Phase C/D of the OTV accommodations program. It is unknown at this time if a TDM in this area is required on the Space Station. See Volume IV Technology Development Plan for further detail.

Figure 7-4 shows the development schedule for the other area of space operations technology, namely on-orbit servicing and maintenance which also includes docking/berthing and payload mating. Servicing and maintenance involves both the SBOTV and the OTV accommodations themselves.

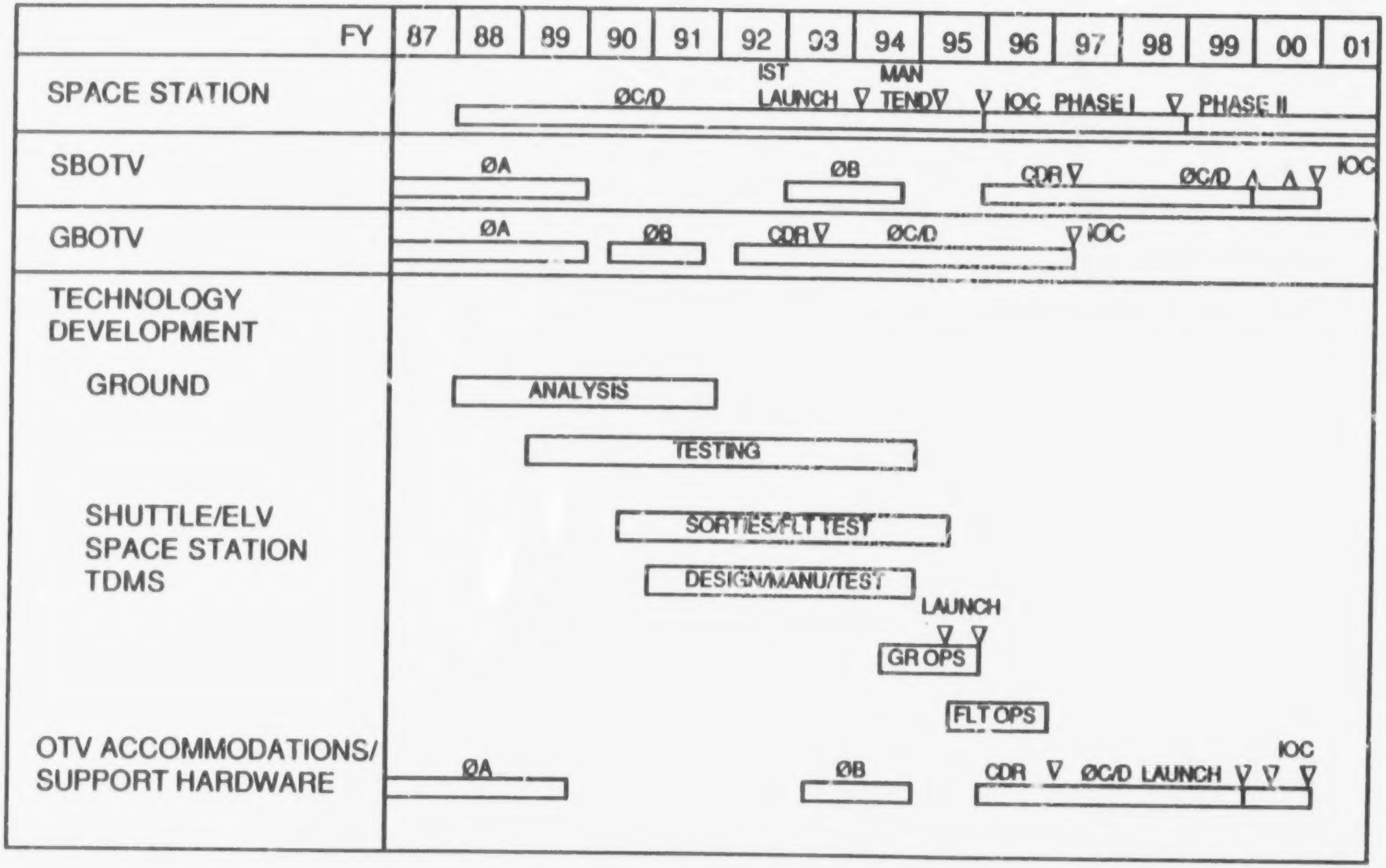

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Figure 7-1. Design and Development Schedule for OTV Accommodations/Support Hardware

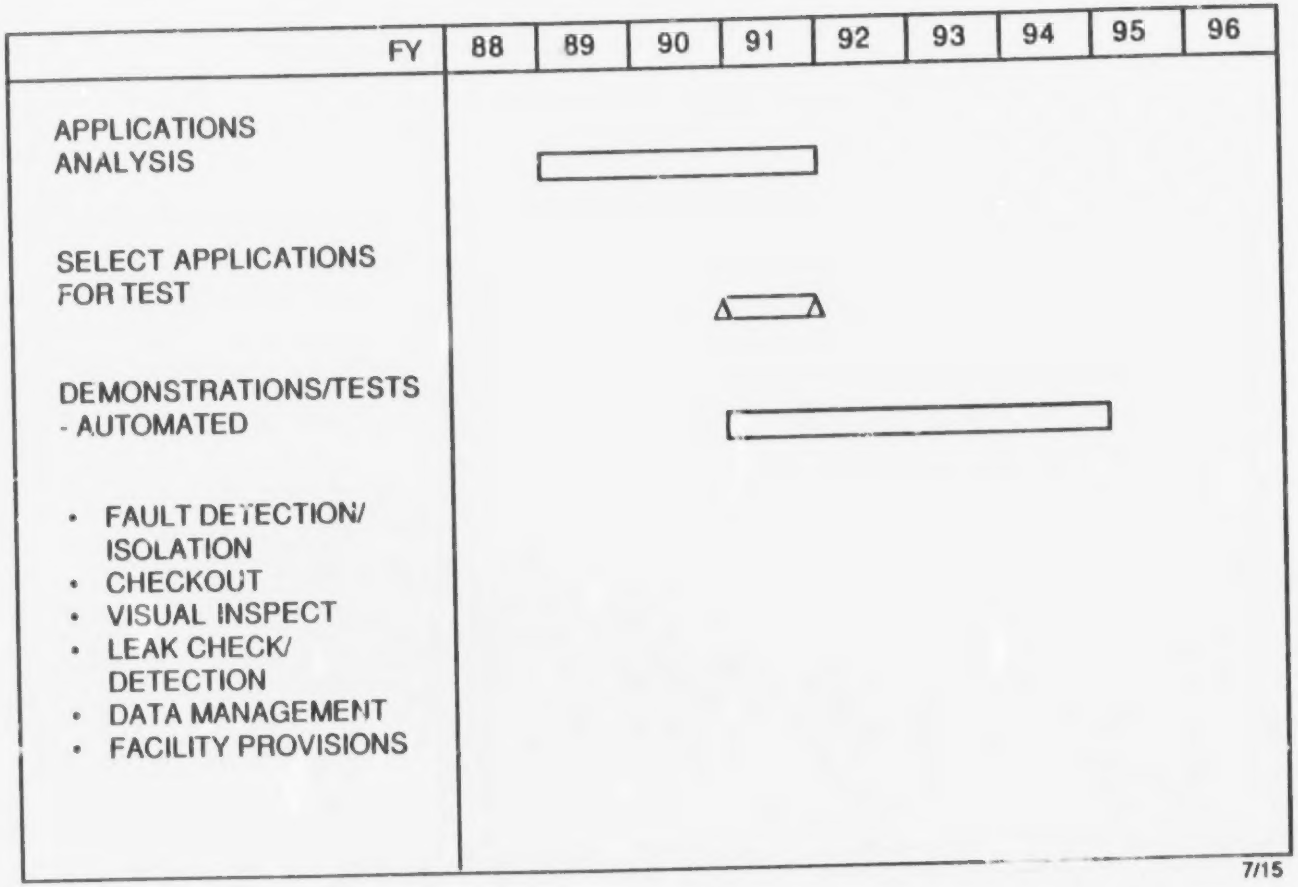
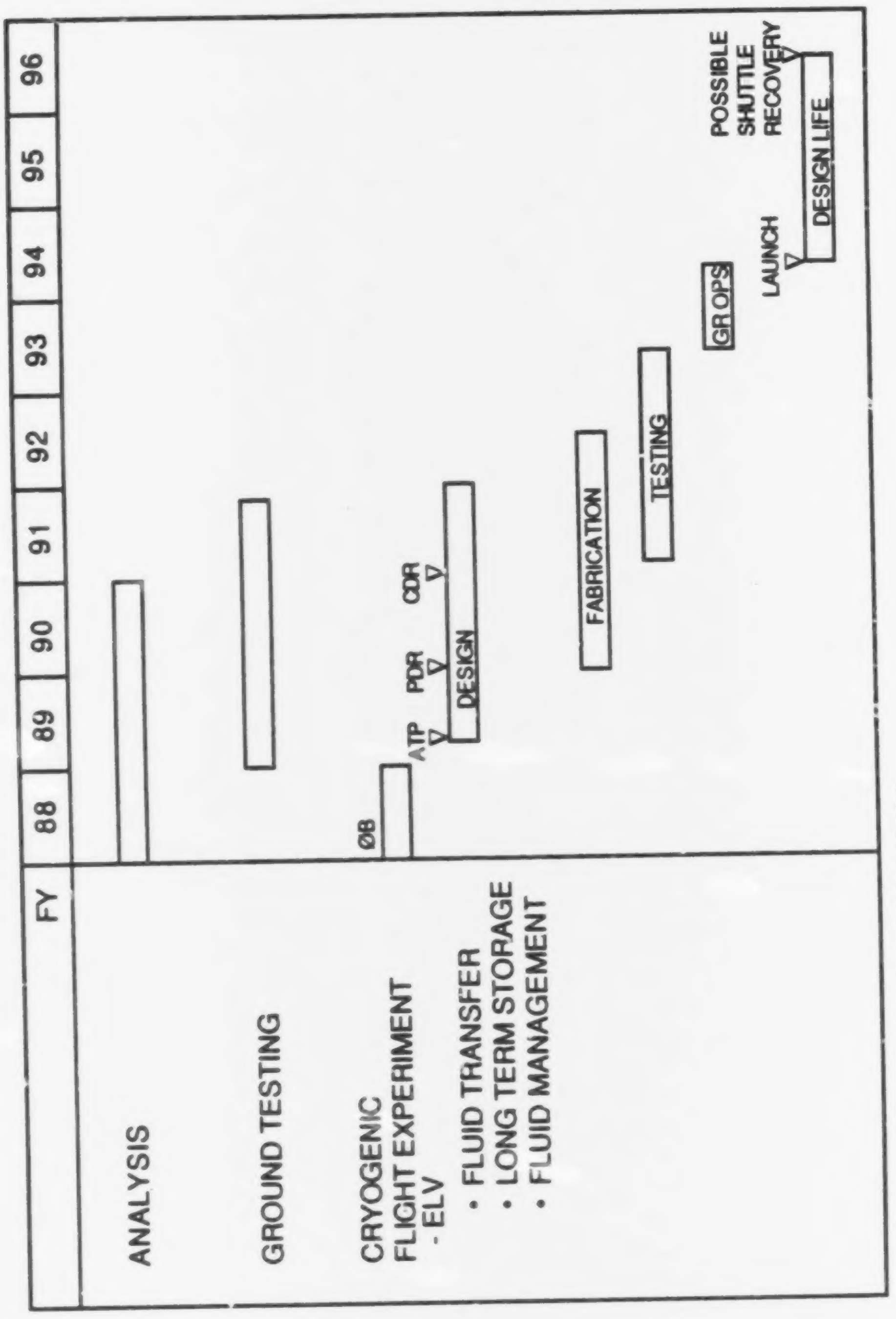


Figure 7-2. OTV Accommodations/Support Hardware Technology Development: Ground Operations



*MAY REQUIRE SPACE STATION TDM

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Figure 7-3. Technology Development: Space Operations OTV Accommodations/ Support Hardware

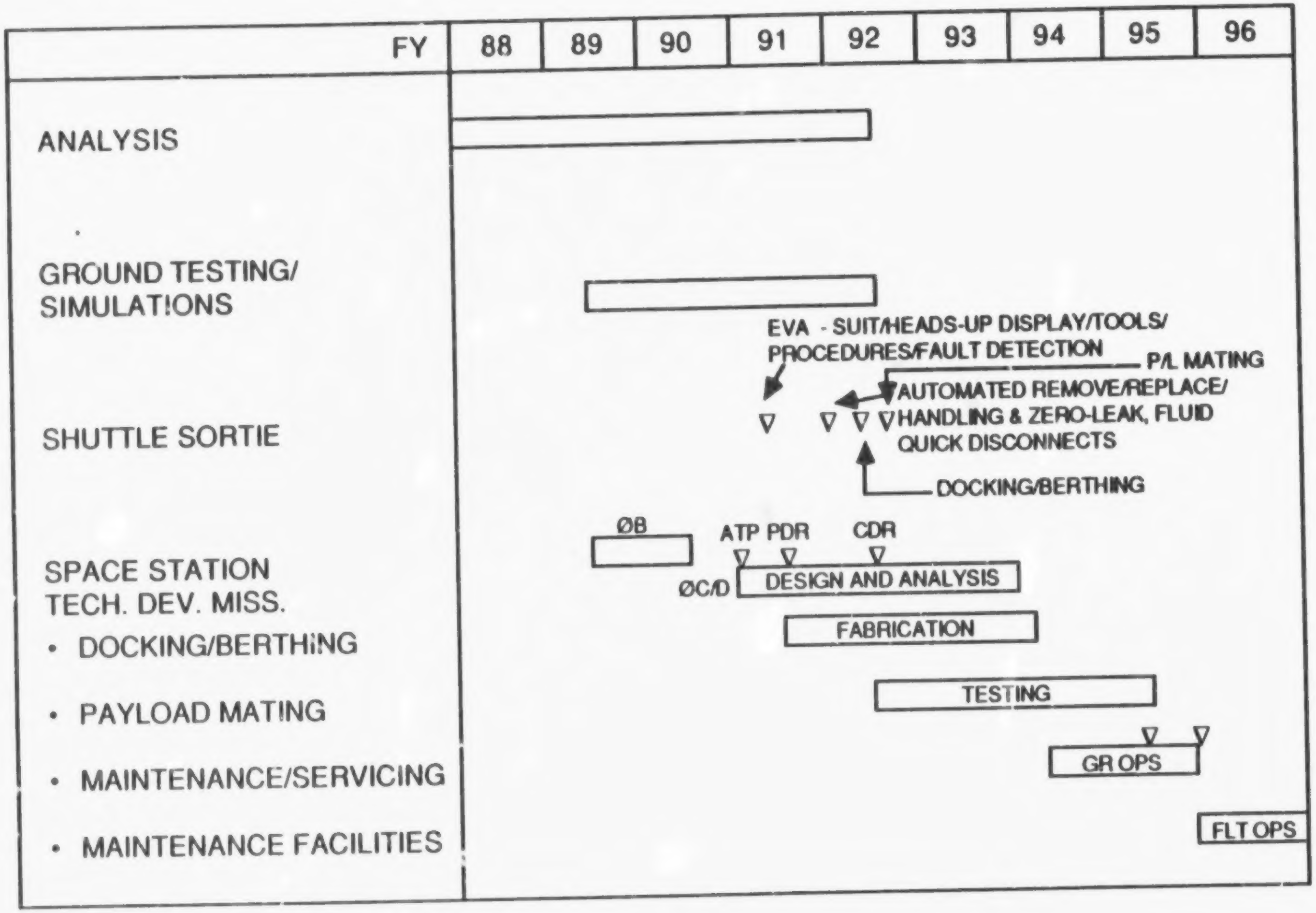

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Figure 7-4. OTV Accommodations/Support Hardware Technology Development/ Space Operations

The technology development plans include ground testing/simulations, Shuttle sorties, and a TDM on the Space Station. Proposed Shuttle sortie missions would evaluate the various elements of servicing and maintenance shown on the chart in zero-g. These sortie flights would be accomplished before the CDR for the Space Station TDM.

The Space Station TDM would be launched in 1995 and be ready for the flight operations in 1996 at the IOC of the station. The data collected would provide verification of the design and approach during the Phase C/D of the SBOTV and OTV accommodations.

It is unknown at this time if a TDM for propellant transfer/long-term storage is required on the Space Station.

7.2 DEVELOPMENT AND OPERATION COSTS

Listed below are the ground rules and assumptions integral to the development of the Space Station OTV accommodations program cost estimates:

a. Cost estimates are in constant 1986 dollars.

b. No fee contingency or government support is included.

c. System estimates include nonrecurring and recurring costs of the OTV accommodations.

d. SBOTV IOC is 2001.

e. Space Station costs are included for use of IVA support, EVA support, EVA support, RMS usage, and power consumption.

f. A composite labor rate of $43 per hour is used for all ground support labor.

g. EVA manhours are charged at 81.715k/crew hour.

h. Vehicle development, production, and spares are not included in this estimate.

i. Ground facilities and support equipment are not included in this estimate.

Table 7-1 lists the accommodations nonrecurring costs.

The accommodations operations program includes all recurring tasks associated with SBOTV turnaround and accommodations operations and maintenance. These numbers are displayed for an average OTV flight rate of 15 per year (see Table 7-2).

The funding requirements for the OTV accommodations program (shown in Table 7-3) are the $1.4 billion development program and the $33 mission average operations cost. This profile defines a peak funding requirement of $270 million in 1994 and a 10-year operational life cycle cost of 1.7 billion.

		DDT&E		PRODUCTION
ELV TDMS		200		N/A
SS TDMS		107		N/A
OTV ACCOMMODATIONS		849.1		226.1
OTV HANGAR	37.2		32.7	
BERTH & POSITIONING	96.5		9.4	
PROP. STORAGE	257.0		121.9	
CONTROL & C/O	311.5		50.5	
MAINT. EQUIPMENT	146.9		11.6	
TOTAL		1156		226.1

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Table 7-1. Space Station OTV Accommodations Non-Recurring Costs (1986 $M)

ANNUAL SPACE STATION OPS COSTS	MANHOURS		ANNUAL COST (1986 $M)
	IVA	EVA	
OTV TURNAROUND (AVG @ 15 FLT/YR)	827	73	21.5
PROPELLANT RESUPPLY	153	0	2.9
EQUIPMENT MAINTENANCE	80	41	4.9
LONG TERM CRYOGENIC STORAGE FACILITY	63	36	4.1
ANNUAL OPS COST	1123	150	33.4

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Table 7-2. Space Station Accommodations Operations Costs

	88	89	90	91	92	93	94	95	96	97	98	99	00	01	
ELV EXP (CRYO PROP 1/10)		6.0	20.0	39.0	47.0	44.0	40.0							IOC ∇	
SS TDM (MAINT/SERVICE)				2.0	12.0	15.5	14.0	5.0							
GR & SORTIE TESTS	2.7	10.2	19.9	18.5	9.0	30.5	30.3								
ACCOM DDT&E					73.8	193.8	241.8	206.2	112.0	21.4					
ACCOM PROD									13.1	58.7	82.5	58.7	13.1		
ANNUAL OPS														33.4*	→
	2.7	16.2	39.9	59.5	141.8	283.8	326.1	211.2	125.1	80.1	82.5	58.7	13.1		= $1.44B

*ANNUAL OPS AT STATION

DOESN'T INCLUDE LAUNCH VEHICLE COSTS
OPTION #2 CRYO PROP DEV

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Table 7-3. Space Station OTV Accommodations Funding Requirements (1986 $M)

SECTION 8

CONCLUSIONS

The following are the lessons learned from processing the Shuttle Centaur, which we inputted into the analysis and trade studies on the OTV:

a. Semi-automated cryo stage easily extended to full automation.

b. Identified manual operations: Candidates for automation.

c. ASE for cargo bay GBOTV will be complex (dump and dual-fault-tolerant).

d. Integrated facility recommended.

e. Facility should provide capability to simulate launch vehicle interfaces and Space Station interfaces for SBOTV.

f. Reduce number of physical moves.

Figure 8-1 summarizes how the ground processing analysis progressed from the Shuttle/Centaur data through the expendable and cargo bay OTV alternatives to the other OTV concepts and then on to the space processing.

GDSS used the manhours expended on processing the first Shuttle Centaur through ELS up to launch as our starting point. We modified those numbers to eliminate nonprocessing-related tasks to come up with the 39,000-manhour number. We modified that number to project what we thought it would take to process a Shuttle Centaur on a nominal schedule of several a year.

From this data we investigated what tasks it would take to process an OTV. We looked at Shuttle/Centaur-type facilities and task to start with and then projected what it would take for other facilities and types of tasks. The differences between the operations are identified on the chart.

After we analyzed the cargo bay OTV alternative processing tasks, we applied this knowledge to come up with manpower and times for the other OTV concepts.

For space processing, we used the Shuttle/Centaur and OTV ground data as a data base. We modified the ground processing data to eliminate tasks that were not needed at the Space Station. We then analyzed these tasks to come up with approaches and manpower to perform them in a space environment. The recommended manhours for space crewmen and personnel on the ground to perform these tasks are shown on the chart.

The following summarizes the major results of the analysis performed on the study:

a. Shuttle/Centaur ground processing operations provided detail data base to identify efficient ground and space processing for future OTVs.

b. Efficient ground processing (GBOTV) requires integrated facility and automated processing operations.

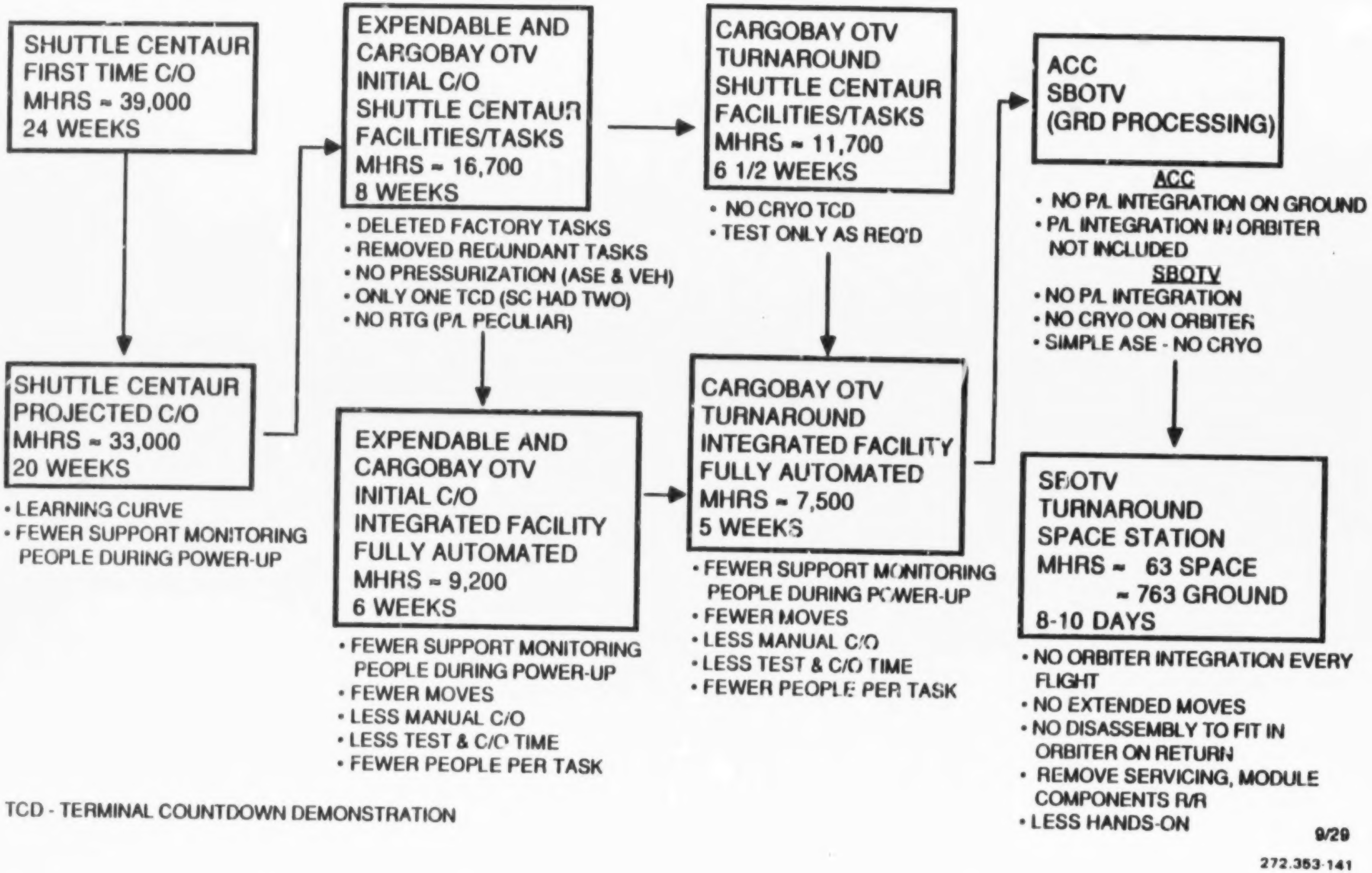

Figure 8-1. Ground Processing Progression to Space Processing

c. SBOTV can be based at Space Station and turned around in safe and cost-effective manner.

d. Minimum SCARs required on initial Space Station for SBOTV.

e. Development of GBOTV operation technology requires analyses, simulation and ground testing of automated fault detection/isolation and checkout system.

f. Development of SBOTV accommodations technology requires analyses, simulation, ground testing and space testing of cryogenic propellants and maintenance/servicing operations/support equipment.

SECTION 9

RECOMMENDATIONS FOR FURTHER STUDY

- DEFINE PREFERRED OTV CONCEPT(S) AND PROGRAMMATIC APPROACH(ES) FOR DEVELOPMENT OF A LOW COST OTV THAT CAN EVOLVE AT THE APPROPRIATE TIME FROM A GROUND-BASED CONCEPT LAUNCHED ON APPROPRIATE EXPENDABLE LAUNCH VEHICLES TO A SPACE-BASED CONCEPT BASED AT THE SPACE STATION OR A FREE FLYING ORBITAL TRANSPORTATION FACILITY.

- INVESTIGATE CANDIDATE ORBITAL TRANSPORTATION SERVICING FACILITY (OTSF) CONCEPTS PROVIDING VARIOUS COMBINATIONS OF SPACE TRANSPORTATION NODE FUNCTIONS IN SUFFICIENT DETAIL TO PERFORM A SYSTEM LEVEL TRADE-OFF WITH AN INTEGRAL SPACE STATION FACILITY TO DETERMINE THE BEST APPROACH. PERFORM A CONCEPTUAL DESIGN OF THE RECOMMENDED APPROACH AND IDENTIFY ITS OPERATIONAL REQUIREMENTS.